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POST-CRETACEOUS HISTORY OF THE MOUNTAINS OF CENTRAL WESTERN WYOMING

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PART II

Later Tertiary planation.—Whether or not the early Tertiary formations ever covered the entire district, it is evident that they have been stripped from large areas which they formerly occupied; for scattered outliers are now situated several miles beyond the edge of the continuous outcrop. It is also an obvious fact that large quantities of the original Tertiary strata have been carried away by erosion in the broad basins themselves. The deformation which succeeded the laying-down of the sediments, probably about the middle of the Miocene, must have initiated a new cycle of erosion, and subjected to denudation large tracts which had previously been sites of aggradation. In later pages it will be shown that between the Miocene and the present there have been several erosion cycles, and the interpretation of those cycles forms an important part of this essay. The data for this must be drawn largely from the features of the existing topography, now to be considered.

The central part of the Wind River Range is in reality a broad dissected plateau 20–30 miles wide, surmounted by a narrow axial range of sharp peaks. The plateau is no longer complete

but rather consists of numerous tabular remnants,[1] which the eye can easily combine and thus reconstruct in imagination the original surface (Figs. 12, 13, 14). Such a reconstruction suggests a region reduced largely to flatness, but with subdued mountains and hills with a relief of less than 1,500 feet near the divide, i.e., a state of early old age. The topography was largely independent of rock structure, passing indiscriminately

FIG. 12.—Photograph of Green River lakes and Square Top Mountain, a remnant of the summit peneplain. Photograph by C. L. Baker.

across hard and soft members of the Archean complex and also across the alternately hard and soft Paleozoic strata. In 1909 this was recognized as a peneplain by C. L. Baker;[2] and Westgate and Branson[3] in a later paper described a similar feature at the

[1] See the Fremont Peak, Wyoming, topographic sheet of the U.S. Geological Survey.

[2] C. L. Baker, "Cenozoic History of Western Wyoming," *Bull. Geol. Soc. Am.*, XXIII (1912), 73 (abstract).

[3] L. G. Westgate and E. B. Branson, "Later Cenozoic History of the Wind River Mountains," *Jour. Geol.*, XXI (1913), 142–59.

southeast end of the Wind River Range. Instead of assuming the origin of the plain, it is fitting that we examine the question before proceeding.

It is apparent that the plateau surface is a cut plain, with residual hills and mountains still standing above it. There appear to be three methods by which extensive cut plains may be produced in the interior of a continent: (*a*) by the action of ice-sheets;[1] (*b*) by the long-continued action of the wind; (*c*) by river systems that have endured to old age.

FIG. 13.—Mountain ridge (11,500 feet) near Gypsum Creek at the west end of the Wind River Range, showing a syncline in Paleozoic rocks cut off at the level of the peneplain.

There is so little in favor of the hypothesis that the plain was produced by ice-sheet glaciation, that it may be quickly dismissed. It will be shown that the plain is one of the oldest topographic features in the district and therefore probably pre-Quaternary. It now carries locally upon its surface deposits of residual soil. There is no evidence of general ice-sheet glaciation in the surrounding districts. It would have to be assumed that the present axial range has been developed since the ice sheet disappeared, for ice sheets inevitably tend to destroy rather than to make such features,

[1] F. E. Wright, "Effects of Glacial Action in Iceland," *Bull. Geol. Soc. Am.*, XXI (1910), 717–30.

and would almost surely succeed if they persisted so long as to planate the surroundings.

It seems to be established that prolonged wind abrasion in deserts does produce plains on which only scattered elevations remain; although the criteria for recognizing ancient wind-made plains are hardly as well agreed upon by physiographers as are the criteria for peneplains. Such a plain, if undefaced, should have certain characteristic features which could be used in recognizing its origin. Its depressions should be broad, relatively flat-bottomed

FIG. 14.—Photograph of mountain (11,500 feet) near Gypsum Creek. Tilted Paleozoic limestones trunkated at summit.

hollows, rather than graded valleys, and these hollows should have a definite relation to the weakest rocks. Wherever hard and soft rocks are exposed there should be the characteristic wind-etched ridges, ledges, mushroom rocks, etc. The pebbles in the gravel strewn upon the flats by occasional floods should be pitted, polished, and even beveled by the sand-blast. Only the most massive and resistant bodies of rock should stand out as hills and mountains.

Unfortunately it is almost impossible to apply the test of these criteria to the Wind River plateau in its present condition. The details of its surface forms and material have been greatly modified by the long-continued action of frost above timber-line. The

trenching of the plateau by many canyons, and especially the scouring of its surface by widespread alpine glaciers in a comparatively recent epoch, have generally effaced the original details of its topography. The higher mountain peaks do not, however, appear to have any relation to especially hard rocks, but rather form a definite range or divide near the crest of the anticline. In short, if the plain was largely fashioned by wind action, all evidence of the fact seems to have disappeared.

The competency of streams to reduce hard and soft rocks alike to monotonous relief, without removing the last residual mountains, is generally admitted. Upon such a plain there should be only thin alluvial deposits and widespread residual soil. It is an observed fact that on the southwest side of the Wind River Range

FIG. 15.—Drawing (from a photograph) of Wind River peneplain and range as seen from Triangle Peak in the Gros Ventre Range.

deposits of soil, several feet deep, due to the decay of the granitic rock in place, still exist upon the tops of mountains 11,300 feet high, which constitute a part of this or a still younger plain (Fig. 16). Since the original drainage can no longer be seen, and since in all but a few places topographic detail has been modified by subsequent glaciation, the evidence directly in favor of river erosion is but little more satisfactory than that for wind action. The most significant fact is perhaps the continuous range of peaks, forming a divide independent of rock structure. Such divides are characteristic of stream-made topographies, but of no others. As the problem now stands there is then only a measure of probability, but not proof, that streams were the agents of planation; and so, for convenience, the old plateau surface will be called in later pages a "peneplain," implying thereby only that it was produced by the long-continued action of degrading agencies.

If reconstructed by filling the depressions cut out of it, the summit peneplain would stand forth as a gently undulating

surface, surrounded by many low hills and even mountains of gentle slope, rising to a distinct divide now marked by the crest of the Wind River Range. Unmarred remnants of this surface are believed to exist still in Goat Flat, the high plateau west of West Torrey Creek, the flats both north and south of Clear Creek and other similar features ranging from about 12,000–13,000 feet in altitude, and declining near the outer borders of the range to about 11,300 feet. As a result of two or three stages of glaciation, the slopes of the once broad, residual hills and especially the axial

FIG. 16.—Residual soil from granite, a remnant of the Wind River peneplain, now at 11,300 feet, Gypsum Creek.

divide have been excavated and made much steeper than before. To this process I ascribe the existing sharpness of the peaks and arêtes of the range. The broad plateau remnants at 10,000–10,500 feet east of Pinedale may not be parts of the summit peneplain, but rather the result of a later cycle.

Although the ancient peneplain has since been widely demolished by erosion, other remnants of it than the Wind River plateau should exist; but a search of neighboring ranges brings unsatisfactory results. The Mount Leidy highlands, to the northwest, are so maturely dissected that no ancient flats remain at high elevations. The flats at 11,000–12,000 feet in the Absaroka Range

may well belong to the same stage, but they are less significant because they lie upon horizontal strata. The more or less level crest of the Hoback Range, at 9,000–10,000 feet, is somewhat more suggestive of planation. This range consists of highly folded hard and soft rocks, which if planated and then dissected would cause the sculpturing of level-topped ridges. This type of topography prevails southward along the Wyoming Range and is conspicuous near Labarge Mountain northeast of Kemmerer. Along the crest of the Gros Ventre Range and especially in the western half there are some flats of considerable area at elevations of 10,300–10,800 feet. These have been cut across strata of varying hardness tilted at angles of 10–50° on both flanks of an anticline. However, it should be noted that they lie 1,000–2,000 feet lower than the Wind River plateau. As the mountain ridges to the southwest are considerably lower (8,000–9,500 feet), they may belong to later peneplains, unless the Wind River surface has been notably warped.

From the canvass of the district it appears that the peneplain is preserved best on the very massive hard rocks of the broad Archean outcrop in the Wind River Mountains. Somewhat doubtfully I correlate with this the smaller flats along the crests of ranges where hard folds in Paleozoic rocks have been trunkated. Over the intervening territory the weakness of the Mesozoic and Tertiary rocks has enabled the streams to destroy the peneplain.

In the Teton Range there is a broad expanse of the massive Archean formations, and hence the preservation of another large peneplain remnant might be anticipated. Instead we find an extremely rugged surface with but few small elevated flats. The east base of the range is marked by a fault of more than 10,000 feet displacement, along which the soft Cretaceous shales and Tertiary clays have been brought down to the level of the massive Archean gneiss. There is good evidence that this fault is not younger than the mid-Tertiary epoch of diastrophism. Urged by such conditions, the rejuvenated streams are believed to have rapidly excavated Jackson Hole from the Cretaceous and Eocene beds, thus leaving the Archean mass of the Tetons to form a wall of imposing height along the west (Fig. 17). Consequent streams on the face of the wall were able to cut only short steep gorges in the block,

while the Snake River was rapidly excavating the adjacent beds of clay and shale. That portion of the peneplain upon the

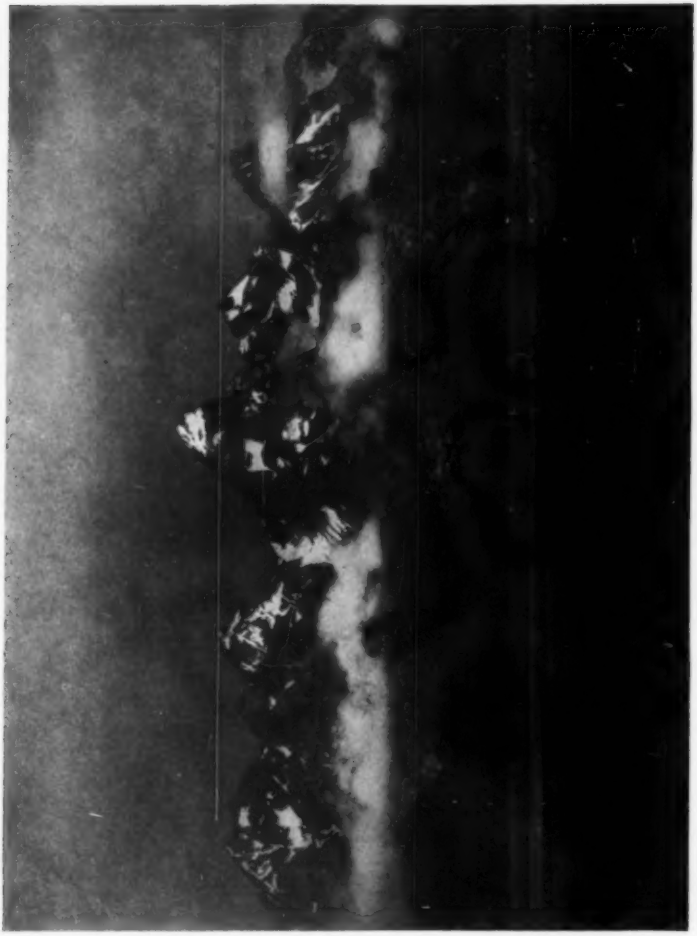

FIG. 17.—The eastern front of the Teton Range, including the Grand Teton. (Photograph by Stimson)

Teton block thus found itself in a position particularly vulnerable to the attack of streams and glaciers, and hence it has been carved into ruggedness more rapidly than other uplifts. Nevertheless

at least two small remnants of an apparent peneplain still exist north of the Grand Teton; one is the flattish summit of Mount Moran (12,100 feet) and the other a triangular flat summit at 10,000 feet on the north side of Birch Creek several miles to the west. Only the latter of these has ever been examined by a

FIG. 18*a*.—Waterworn cobbles of quartzite among limestone fragments on the flat summit of a peak (10,100 feet) in the Teton Range.

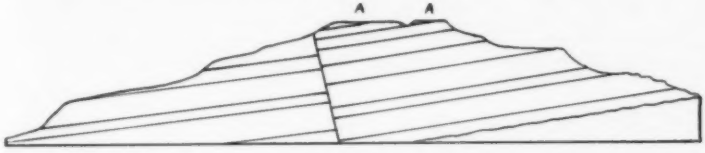

FIG. 18*b*.—Diagram of the occurrence of the gravel shown above. The gravel lies on the surfaces (*AA*).

geologist (Figs. 18*a* and 18*b*). Its surface is strewn with the usual frost-cracked débris of the underlying Madison limestone, but also with well-rounded cobbles of quartzite which still retain their original polish. That this is a bit of an old stream-worn surface is thus clearly shown. It may be a part either of the Wind River or later peneplains, or of the unconformity at the base of the Pinyon conglomerate. It may be argued that the peneplain would not

be likely to have coarse gravel upon its surface. The surface underlying the Eocene formations, which is gravel-strewn, has already been described as being rugged.

In Yellowstone Park the formation of the peneplain may have been prevented, or if it was made, it may have been overwhelmed, by the volcanic eruptions which students of that district assign to the Pliocene and later epochs.

Turning to other parts of the Rocky Mountains, I find elevated peneplains widespread. In the Bighorn Range[1] there seems to be a similar high plateau surmounted by an axial mountain range, which, prior to the cirque-making by Quaternary glaciers, had a subdued post-mature topography. There also the eroded surface trunkates the various rock structures indiscriminately. In another place[2] I have described the peneplain which is well preserved in the Sherman Mountains of southeastern Wyoming. Other cases of somewhat similar characteristics have been reported from Colorado, Montana, Idaho, Washington, and other western states. These peneplains have been assigned to the Eocene, Miocene, and Pliocene,[3] but they are so similar in their characteristics and relations as to suggest that they may be only local remnants of a once widespread old-age surface, subsequently more or less warped.

The age of the Wind River summit peneplain is debatable, but, by a process of finessing, it may be worked out with some degree of assurance. It will be admitted by all that, since it trunkates the structures produced by the folding at the close of the Cretaceous, it must be of Cenozoic age. The stage of topographic old age, when planation is being accomplished, does not permit the accumulation of thick sedimentary deposits in the same district because the two processes are mutually exclusive. This appears to be true whether the work is done by wind or by streams. For that reason it is hardly conceivable that the peneplain could have been developed while the Eocene and Oligocene strata were being deposited to thicknesses of several thousand feet in various parts

[1] See Plates VIII A, XXVII A, XXX, and XXI A, in "Geology of the Bighorn Mountains," by N. H. Darton, *U.S. Geol. Survey, Prof. Paper 51*, 1906.

[2] *Jour. Geol.*, XVII (1909), 429–44.

[3] See p. 194.

of the same region. If this inference is sound, the peneplain must have been made either just before or just after the Eocene-Oligocene epoch of deposition. We may first consider the hypothesis that the peneplain is part of the pre-Wasatch (Lower Eocene) topography.

The eroded surface which underlies the Eocene strata is clearly exposed at many points among the ranges of western Wyoming. Where it trunkates the soft Mesozoic strata, this surface is relatively flat, but on the harder rocks nearer the axes of the ranges, it is hilly and even mountainous in relief. Thus in the southwest part of the Kirwin quadrangle, between Double Diamond ranch and Mountain Meadows, the Wind River Eocene beds rest upon an eroded surface which has a visible relief of more than 1,200 feet. Immediately upon it there generally lies a coarse conglomerate (Pinyon) of variable thickness. Northeast of the Gros Ventre Range this reaches a thickness of about 1,000 feet, and on the south side it is apparently even thicker. From these facts we seem compelled to infer that there were conspicuous hilly or mountainous tracts when the early Wasatch deposits were laid down, and that streams later leveled up the lesser inequalities with their deposits.

As a second test of the hypothesis of Eocene age, attention should be turned to the relation between the peneplain and the Eocene formations, for if those relations are clear they may decide the age of the plain. The Eocene deposits now generally lie at much lower elevations than the existing remnants of the peneplain, and the basal contact in some places is more than 6,000 feet below it. I can conceive of but three ways (Fig. 19) in which this could be brought about: (*a*) the Eocene sediments may represent the filling of Eocene valleys excavated in the peneplain; (*b*) they may be remnants of once horizontal deposits laid down upon the peneplain and now preserved by down-warping or down-faulting; or (*c*) they may be bodies of sediment, either deposited in earlier depressions or warped or faulted down, upon the surface of which, together with adjacent formations, the peneplain has subsequently developed. In the first two cases the age of the peneplain would be pre-Wasatch. In the last case it would be post-Oligocene. These three possibilities will now be examined briefly.

If the Eocene sediments were deposited in basins excavated below the peneplain, the sediments should have been derived in part from the slopes and divides of the basins themselves. On both sides of the Gros Ventre Range, however, the thick coarse conglomerate in the Lower Eocene consists not of local rocks but almost entirely of varicolored quartzite with occasional porphyries. Since there are no rocks of this character entering into the make-up of the Gros Ventre Range, these pebbles must have been imported; and the nearest appropriate outcrops are about 100 miles to the northwest.

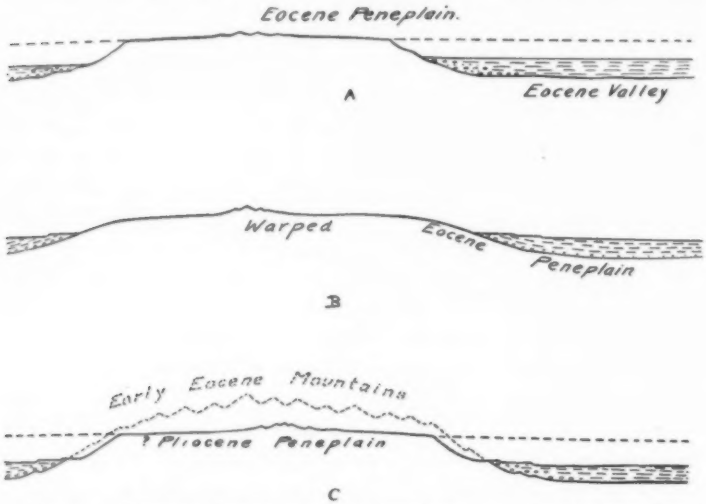

FIG. 19.—Diagrams illustrating various hypotheses as to the relation and age of the peneplain: (*a*) as an Eocene plain with valleys excavated in it and then filled; (*b*) as an Eocene plain covered with sediments and then warped; (*c*) as a Pliocene (?) plain cut across Eocene and older rocks.

Considerations of time are also somewhat adverse, since upon this hypothesis the planation, involving the most massive and resistant rocks, must have been completed in that fraction of the Eocene epoch between the folding of the Paleocene (Fort Union) strata and the deposition of the Lower Eocene (Wasatch) beds. In the same interval of time, spacious depressions must also have been excavated beneath the new peneplain for the reception of the

Eocene sediments. On the other hand, the remnants of the peneplain must have been preserved on a large scale from the early Eocene to the present. Without convincing evidence in its favor this is not, therefore, an attractive hypothesis.

On the supposition that the surface we now find beneath the Eocene sediments is part of the old peneplain, which has merely been warped and partly uncovered in subsequent time, we should anticipate that the softer Paleozoic and especially the Mesozoic strata would be reduced to base-level long before the massive granitoid rocks of the Archean were worn low. Nevertheless, there is abundant evidence that the basal Eocene surface was only maturely hilly upon the outcrops of the Paleozoic and, in some places, of even the Mesozoic strata. That surface was a plain only on the weakest beds. Again, if we are to ascribe the preservation of the Eocene to down-warping after it was deposited upon the peneplain, we should rightly expect to find the Eocene strata parallel to the base on which they rest. On the contrary, in many places they grade horizontally into thick beds of conglomerate which themselves rest against a steeply inclined surface of the older rocks, thus indicating that the beds were actually deposited in a valley or basin and not upon a plain.

To the suggestion that the peneplain is younger than the Eocene sediments, and has beveled them as well as the older rocks, I can find no objection. It is free from the difficulty occasioned by the Miocene deformation of the entire district. It explains the absence of Eocene remnants upon the peneplain and does not conflict with the existence of the rugged basal Eocene contact overlain by horizontal beds. It also corresponds with determinations in other parts of western United States, that the principal peneplains are not older than the Miocene. I therefore accept, for the present, the conclusion that the peneplain is younger than the early Tertiary strata, and later than the mid-Tertiary deformation that expressed itself in warping and faulting.

In subsequent pages it will be shown that a number of events requiring a relatively long time must be referred to the Quaternary period, and there is so much good evidence all over the western states that the opening of that period was characterized by

noteworthy changes of level, that it is probably safe to refer the peneplain to the time between the Middle Miocene and these early Quaternary disturbances.

The complete planation of soft rocks may be accomplished in a geologically short time, but the reduction of very resistant granitoid rocks to a peneplain must require a vastly longer time. Planation of either kind of rocks by streams demands a constancy of conditions which is possible only when the lithosphere is in a state of rest. Inasmuch as such quiet is rarely local only, and if long continued would permit the planation of very large areas, it is worth while to inquire if peneplains were made in adjacent regions, and if so at what time geologically.

Within the past decade several geologists[1] who have independently recognized peneplains in the Rocky Mountains have referred them to late Tertiary time or specifically to the Pliocene. In several other districts somewhat more remote,—the Cascade Range of Washington,[2] the Sierra Nevada in California,[3] and the Grand Canyon of Arizona,[4]—peneplains have been reported and their ages determined as approximately Pliocene. The summit peneplain of central Idaho is assigned by Umpleby[5] to the Eocene, but in a review[6] I have suggested that the opinion is not well founded.

In brief, the evidence from all points of view here considered, although it does not establish the age of the peneplain, does strongly

[1] W. W. Atwood and K. F. Mather, *Jour. Geol.*, XX (1912), 407; S. H. Ball, *U.S. Geol. Survey, Prof. Paper 63*, 1908, 32; E. Blackwelder, "Cenozoic History of the Laramie Region," *Jour. Geol.*, XVII (1909), 437; J. L. Rich, "Physiography of the Bishop Conglomerate, Southwestern Wyoming," *Jour. Geol.*, XVIII (1910), 613 (age given as post-Oligocene, probably Miocene); L. G. Westgate and E. B. Branson, "Cenozoic History of the Wind River Mountains," *Jour. Geol.*, XXI (1913), 144.

[2] B. Willis and G. O. Smith, "A Contribution to the Geology of the Cascade Mountains," *U.S. Geol. Survey, Prof. Paper 19*, 1903, 70.

[3] F. L. Ransome, "The Great Valley of California," Univ. of Calif., *Bull. Dept. of Geol.*, 1896, I, 371–428.

[4] H. H. Robinson, "A New Erosion Cycle in the Grand Canyon District, Arizona," *Jour. Geol.*, XVIII (1910), 742–63.

[5] J. B. Umpleby, "The Old Erosion Surface in Idaho," *Jour. Geol.*, XX (1912), 144.

[6] E. Blackwelder, "The Old Erosion Surface in Idaho: A Criticism." *Jour. Geol.*, XX (1912), 410–14.

indicate that it was Pliocene. At that time western Wyoming must have been in a state of tectonic rest which permitted the streams or the wind, or both, to reduce nearly all of the district to the condition of a peneplain, interspersed with post-mature mountain masses, situated on the most resistant rocks (Fig. 20). Appropriately we find in the region no sediments of presumptive

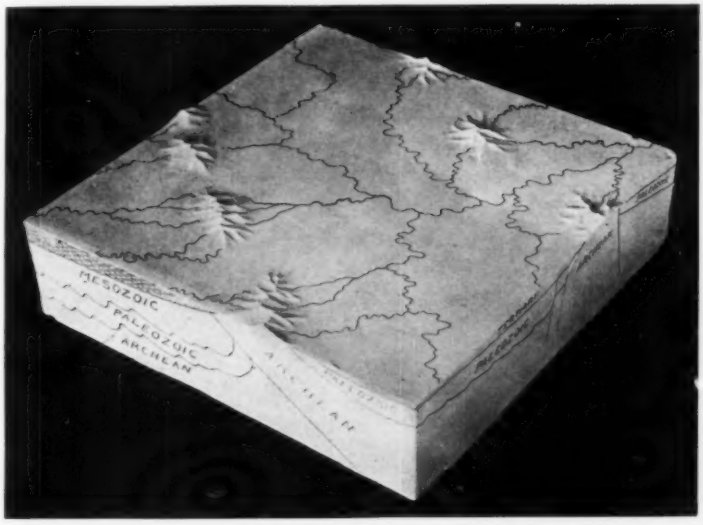

FIG. 20.—Model of a part of the Wind River basin and vicinity as it may have appeared at the completion of the peneplain.

Miocene or Pliocene age and hence know little of the climate, the life, or the changes of the time.

Early Quaternary rejuvenation.—Even where now best preserved, the peneplain is trenched by deep valleys, and over a large part of the district it has been destroyed by their growth (Fig. 21). The remnants now stand at elevations (11,000–13,000 feet) so high that no agency of land sculpture seems capable of fashioning them as they stand. Since the graded streams of the district now flow in channels between 5,000 and 8,000 feet above sea-level, the remaining parts of the peneplain are obviously in a vulnerable

position, and the progressive lowering of grade makes them only more so. The present altitude of the remnants may therefore be ascribed to movements in the lithosphere. Two possibilities suggest themselves: (*a*) local warpings whereby small parts of the peneplain were elevated or their surroundings were depressed; and (*b*) a widespread uniform change of level which incited the erosive agencies to excavate the soft rocks deeply, and so left only remnants of the peneplain standing out in relief, where the rocks were most resistant.

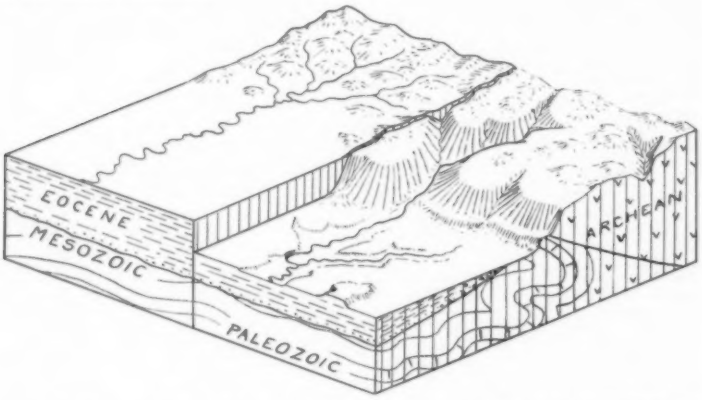

FIG. 21.—Diagram of a part of the Wind River Range before and after the dissection of the peneplain.

If the Wind River plateau be regarded as a local uplift, it may be either a horst or an upwarp (Fig. 22). That it is not the former is sufficiently indicated by the observed fact that it is not surrounded by faults. If it were an upwarp the peripheral slopes would be likely to preserve remnants of the peneplain bent downward but otherwise showing the trunkation of the various structures. I have looked carefully for such features in the foothills of the range, but with negative results. On the contrary, the peneplain comes out to the west front of the range at a nearly constant elevation and breaks off abruptly to the lowlands west of it. These facts suggest that the present contrast between the the isolated plateau and the surrounding plains is not due primarily

to differential warping; but they do not preclude the possibility of warping in a minor degree.

The hypothesis that existing conditions are due to uniform regional uplift followed by selective denudation is the only one

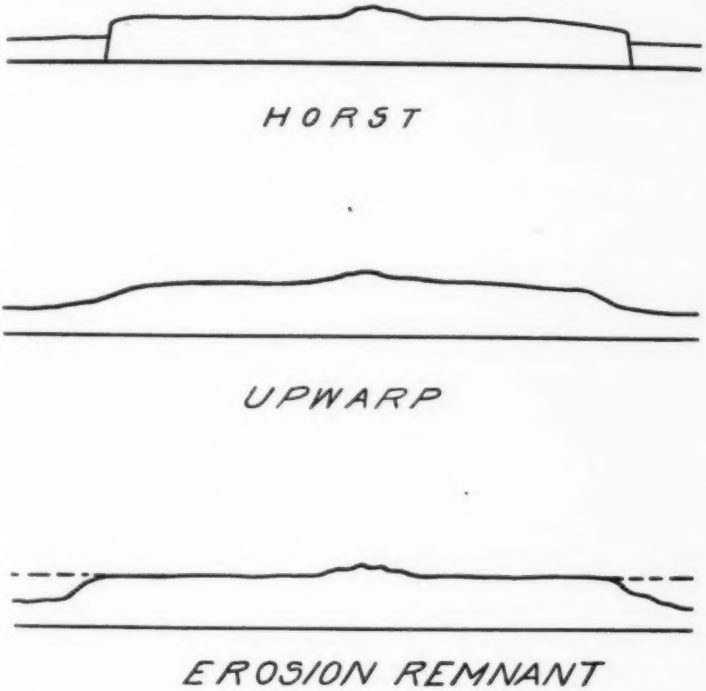

FIG. 22.—Diagrams illustrating the possible origin of the existing Wind River plateau as a horst, an unwarp, or an erosion remnant.

against which I find no serious objections. It agrees well with the fact that remnants of the peneplain now exist only upon the outcrops of the hardest rocks, and with the other fact that these remnants now stand at a more or less common elevation. The hypothesis of regional uplift is therefore accepted tentatively.

Local evidence alone is not sufficient to permit a close determination of the age of this elevatory movement. Obviously it followed the development of the Wind River peneplain, which the available evidence indicates occurred in the late Miocene and Pliocene. In later pages it will appear that there have been several changes of level separated by long intervals of quiet. All, however, seem to have occurred before the last stage of glaciation. It is significant that many of the geologists who have studied the western mountain states have recently concluded that the beginning of Quaternary time was marked by important changes of level, to which the present relief and ruggedness of our western

FIG. 23.—Diagram illustrating the progress of the same erosion cycle in rocks of three different degrees of hardness: (*A*) residual areas of older surface with canyons in granitic complex; (*B*) maturely mountainous surface on Paleozoic limestones, etc.; (*C*) plain on Tertiary clays: (*D*) topography of granitic mountains more advanced than at *A* because of proximity to deep basin.

mountains is in large measure due. These considerations lead to the somewhat indefinite conclusion that the several changes of level occurred between the late Pliocene and the close of the Pleistocene epoch.

General effects of erosion in the Quaternary period.—On every hand there are deep canyons, wide river basins, and other speaking evidences of denudation in geologically recent times. It is reasonable to believe that the district has been subject to erosion under slowly varying conditions and hence with varying results ever since the beginning of the uplift which seems to have accompanied the close of the Tertiary period. Although I am not disposed to belittle the efficiency of the wind in fashioning topographic details, nor in deporting dust from the region and in that way gradually lowering its elevation, it is clear from their forms that nearly all the coarser and many of the finer topographic features of western Wyoming have been carved by running water, and that in general the topography of the district has been under the control of the three prin-

cipal water drainage systems—the Snake, the Green, and the Bighorn. Glaciation and eolation have merely modified the effects of erosion—the one locally, the other generally.

Before proceeding to describe the effects of stream denudation in the district, attention is called to the fact that the surface is underlain by a great variety of rocks which differ vastly in the resistance which they offer to erosive processes. Under a subarid

FIG. 24.—Plane surfaces developed upon the Wind River Eocene beds on the flanks of Black Mountain, in the Wind River basin.

climate, the Tertiary sandy clays are the weakest rocks; the massive Archean gneisses and granites stand near the other extreme of resistance. Between them all gradations exist. It is evident that in the softest of these materials, erosion proceeds with great rapidity in contrast with its progress upon the most refractory formations. This fact (in addition to the structure) is the key to the origin of the principal topographic features of the region (Fig. 23).

In the notably weak beds of Tertiary and Cretaceous age, broad plains have been developed at elevations several thousand feet below the surrounding highlands (Fig. 24). Good examples

of these are the Wind River basin, Jackson Hole, Teton basin, Bighorn basin, Green River valley, and many others outside the district here considered. In these wide basins the younger rocks, down to the more or less resistant Triassic(?) red beds, or even down to the Carboniferous terranes, have nearly all been planed off to a common level. It is highly probable, however, that all of

FIG. 25.—Bad-land topography in the Wind River basin. Shows dominance of the effects of running water even in the driest part of the district.

the basins were formerly filled more or less completely with the soft Tertiary strata, and that most of the erosion has been accomplished in them rather than in the older rocks beneath. All are still partly filled with formations of that age, and outliers show a much more complete filling before erosion occurred.

The floors of these basins are by no means simple flats (Fig. 25), but the details will be discussed more fully in later pages.

At the intertwined headwaters of the three great river systems, the valleys are still narrow and in part ungraded. There, even

upon the soft Cretaceous and Tertiary beds, erosion has produced only a maturely dissected surface (Fig. 26). In this district the peneplain has been wholly destroyed, and it is improbable that any of the summits now rise to its former elevation.

In the moderately resistant limestones, sandstones, and interbedded shales, which constitute the Paleozoic sequence, erosion has proceeded much less rapidly than in the soft Mesozoic and Tertiary formations. Thus where the former rise to the surface we find them only maturely dissected into ramifying V-shaped

FIG. 26.—Mature topography developed on weak Cretaceous and Eocene strata along Fish Creek, near the Continental Divide.

valleys separated by skeleton ridges, or, where folded, into parallel mountains and valleys. The topography of the Gros Ventre Range and of the west slope of the Teton Range, as well as of mountains farther south along the state boundary, illustrates this phase of topographic development.

Erosion has had the least effect upon the hard, massive, and tolerably uniform granites and gneisses of the pre-Cambrian complex. In the district under consideration there are but six localities where these ancient rocks reach the surface, and in three they have merely been uncovered in the bottoms of mountain canyons. The only expansive outcrops at high elevations are those in the Teton,

Wind River, and Owl Creek ranges. In the Teton Range, the juxtaposition of very hard and very soft rocks along a fault has created abnormally steep slopes,[1] so that the Archean rocks of the

[1] The magnificent east front of the Teton Range can scarcely fail to suggest to the geologist a recent fault scarp, but the consideration of it from various angles in three different seasons has convinced me that it is in fact a "fault-line scarp" (W. M. Davis, *Bull. Geol. Soc. Am.*, XXIV [1913], 187–216) situated along a Middle Tertiary displacement, of which the original topography has long since been destroyed. The facts which suggest a recent fault scarp are the abruptness and continuity of the wall, the comparative straightness of the base, and the triangular facets at the distal ends of the very short steep spurs. The gravel-strewn floor of Jackson Hole seems also

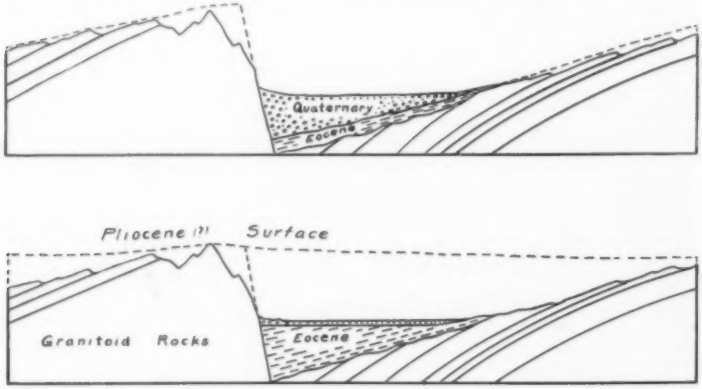

FIG. 27.—Diagrams of the Teton front to explain two possible origins of the escarpment: (*a*) as a modern normal fault scarp; (*b*) as a fault line scarp discovered entirely by erosion.

to indicate the thick alluvial deposits normally made on the downthrown sides of new faults. On further consideration, however, it appears that all of these phenomena may be satisfactorily explained without assuming a recent fault, and there are additional facts which indicate that the scarp was produced by the exhuming of a once-buried fault surface. Such a scarp would be abrupt and continuous, and as straight as the fault trace. In the early stages of dissecting the scarp, triangular facets would be developed at the distal ends of the spurs. The alluvial filling of the Snake River valley is of unknown depth, but the exposures of the underlying rock in several parts of the floor of Jackson Hole suggest that there is only a veneer of alluvium, as in other basins in Wyoming. That the gravel is somewhat thicker in Jackson Hole than elsewhere may be due to the fact that glacial waters from the Jackson Lake moraine poured a large volume of outwash southward along Snake River. (See Fig. 27).

The facts which directly suggest that the fault is an old one, and the scarp due merely to the great contrast in the resistance offered by the rock masses on the east and west sides to erosion, are: (*a*) all other faults within 25 or more miles of this region are old faults, which have lost all original topographic expression; (*b*) it is particularly

uplift have been eroded much more rapidly than they otherwise would have been. The Archean exposures of the Owl Creek Range are not large, and probably did not appear until the last two or three thousand feet of denudation were accomplished. We are reduced, therefore, to a consideration of the Wind River Range as the only part of the district in which the Archean rocks are

FIG. 28.—A typical canyon in the hard Carboniferous rocks of the Wind River Range, twelve miles west of Lander.

broadly exposed and under simple conditions. The Bighorn, Sherman, and certain other ranges in the state should probably be put in the same category.

significant that this is true of the Phillips Canyon fault which appears to join the main Teton fault at an acute angle as if it were merely a branch of it; (*c*) sedimentary rocks to a thickness of perhaps more than 10,000 feet have been removed from the Teton, block since it was first elevated, but these are still preserved in the bottom of Jackson Hole; (*d*) the abruptness and height of the escarpment decrease immediately and markedly toward the north and south ends of the range, as quickly as the outcrops of the less resistant Paleozoic and Mesozoic strata are reached; (*e*) the flat-bottomed part of Jackson Hole coincides almost exactly with the distribution of the weakest Eocene clays and the valley becomes narrow again southward as soon as the Cretaceous outcrops are reached.

In the Wind River uplift deep canyons have been carved out of the granitic rocks, but extensive remnants of the old plateau surface are still preserved upon the interstream divides (Fig. 12). The relative resistance of the hard Archean outcrops is well shown in the channels of many of the creeks that flow out from the Wind River Range. Thus it is generally easy to ascend these valleys as far as they have been cut through the sedimentary strata, but from the base of the Cambrian inward to the axis of the anticline,

FIG. 29.—A canyon in the Archean rocks south of Mount Moran, in the Teton Range.

the Archean outcrop is marked by a series of rapids, falls, and narrow gorges which make even foot travel difficult if not impracticable. Along old faults, which have brought the Archean into contact with some of the weaker members of the sedimentary column—as for example south of the great bend of Green River—the streams have cut merely a few notches in the pre-Cambrian rocks during the time in which the softer sedimentary beds have been completely stripped away to a much lower elevation. This satisfactorily explains why the Wind River plateau has an abrupt front in this locality but not elsewhere.

In short, it appears that the Quaternary has been characterized by widespread changes of level, which in turn have induced the erosion of deep valleys, and that these valleys have been widened in proportion to the weakness of the strata in which they were carved (Figs. 28 and 29). Although there is an advantage in stating the history in these simple terms in order to display the general conditions, it is appropriate to say that the events of the Quaternary have been much more varied and complex than this generalized statement implies. There is good evidence that the uplift or other interruption did not take place once for all at the beginning of the period, nor uniformly throughout the period, but at intervals scattered through a long time. Denudation has been accented by these disturbances, and doubtless also by climatic changes, of which mention has not yet been made. Furthermore, the work of denudation has been done, not only by streams, but in minor degree also by winds, glaciers, avalanches, ground-water, and unaided gravity. This complex chapter of the history may now be analyzed; and, since the changes produced by the different agencies are not in all cases readily correlated, I find it best to treat them separately and in the order of their relative importance.

THE MODE OF ORIGIN OF COAL[1]

EDWARD C. JEFFREY
Harvard University

The question of the manner of formation of coal has divided geologists for over a hundred years and the problem is still disputed, although at the present moment the weight of geological opinion inclines in one direction. Where so much difference of opinion has existed for so long a period, new evidence is obviously much to be desired. The current views as to the origin of coal are based mainly on a consideration of the stratigraphic evidence other than that supplied by the coal alone. For example, much importance has been attached to the presence of underclays beneath the coal beds, as evidence of the existence of an ancient forest soil. Likewise a considerable amount of importance has been attached to the existence of Stigmarian and other root or rootstock systems in the substratum beneath the coal. Comparatively little evidence has been derived from the consideration of the coal itself. Where such evidence has been available it has been of a contradictory nature. For example, certain coals rich in bituminous matter, such as cannels and the like, obviously present in their organization strong resemblances to the muck formed in the bottoms of modern lakes; that is, they consist, to a very large extent, of the remains of spores and pollen. In other cases, much more rare, concretions have been found in the coal, containing quantities of often well-preserved vegetable remains. These remains are of such a character and are related to one another in such a way, that their clearest modern representative is the peat of existing peat bogs. The two kinds of evidence derived from petrified coals on the one hand or from the persistent structures in unmineralized coals on the other appear to justify diametrically opposite views as to the conditions of coal formation. Similar contradictions

[1] *Contributions from the Phanerogamic Laboratories of Harvard University, No. 67.*

apparently present themselves, when the strata below (underclays, etc.) or above (roof strata) the actual coal beds are considered. We have as a consequence the two opposed schools of opinion in regard to the origin of coal. The hypothesis which homologizes the coal bed with an existing peat deposit is known as the autocthonous or *in situ* theory. On the other hand, the view that coal represents an accumulation by floating and sedimentation in the bottom of open lakes or lagoons is known as the transport or allocthonous hypothesis. The evidence for and against these two opposed views has recently been so admirably summarized by Professor John J. Stevenson in his *Formation of Coal Beds* that it appears unnecessary to refer to the subject further at this time.

The purpose of the present communication is to emphasize the importance of the study of the coal itself, in connection with any views as to its composition and mode of origin. The investigation of coal by means of the microscope has presented many difficulties, chiefly because of the opacity and texture of the coal itself. The methods which have been successful in the case of other minerals have not given satisfactory results in the case of coal. The thin ground sections of the mineralogist and petrologist are of little value when the material investigated is coal. If the ground sections are made thin enough to show all of the structural features, these are destroyed by the abrasive effect of the process on the comparatively soft and friable substance of the coal itself. The writer has had considerable experience in investigating the remains of fossil plants in a carbonized condition, a state of preservation which has hitherto been neglected in favor of petrified material. Material in a mineralized condition of preservation is, however, comparatively rarely available, while carbonized vegetable remains are often abundant. A modification of the writer's methods in the case of carbonized Mesozoic plants has been developed as the result of a long series of experiments, and it is now possible to secure satisfactory thin and transparent sections on the microtome of practically all kinds of coals. Obviously this possibility put the question of coal composition and mode of formation on an entirely new footing, as it is now possible to investigate these subjects satisfactorily from the standpoint of the organization of coals of various

geological ages in different parts of the world. The writer has examined coals derived from regions as far apart as Alaska and Patagonia, Dakota and Texas, Washington and Virginia, Great Britain and Japan, Sweden and Tasmania in geographical separation, and in stratigraphic distribution from the Devonian to the Miocene and the present epoch. The results of these investigations have been satisfactorily uniform. We are now apparently in the position to judge of the great problems of coal formation from the all-important aspect of the organization of the coal

FIG. 1

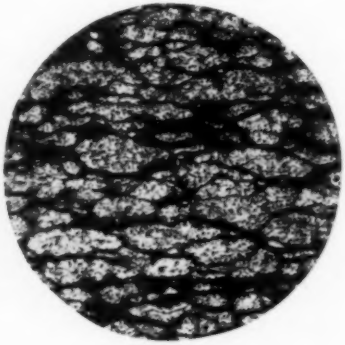

FIG. 2

itself. In other words, we are no longer compelled to infer the nature of coal from the conditions of deposit of the surrounding strata, which may have been laid down under very different circumstances, but we can reach definite conclusions from the structures revealed by the coal itself under the microscope.

Reference has already been made to the fact that certain coals, containing large quantities of spores, are generally admitted to have been formed, not on land as the case with peat, but as sedimentary deposits in open water. Fig. 1 illustrates a notable carbonaceous deposit of this type, namely tasmanite. In the upper part of the figure one spore still retains its rounded contour, but the spore material as a whole, which is very abundant, is represented by the collapsed spore coats, inclosing a linear cavity. Fig. 2 shows the structure of another type of spore coal, an oilshale from

Australia. Here all the spores have collapsed and have rough alveolar exteriors. A remarkable feature of oilshales is the very large amount of spore material present in them, a condition correlated directly with their rich petroleum content when subjected to distillation. A curious error of interpretation has been made in regard to oilshales, bogheads, or bituminous schists, as they have been variously termed. Their structural elements have been regarded by Renault, Bertrand, and Potonié as the remains of delicate gelatinous algae. The present writer, by the improved methods already referred to, has secured evidence that the structures in question are the very rough spores of extinct fernlike cryptogams.[1] It is clear, further, that they cannot be anything of so delicate a nature as algae, since highly modified wood is frequently found in the same matrix with them. It is obvious that gelatinous algae would have quickly been obliterated by influences so powerful as to eliminate the structural organization of wood.

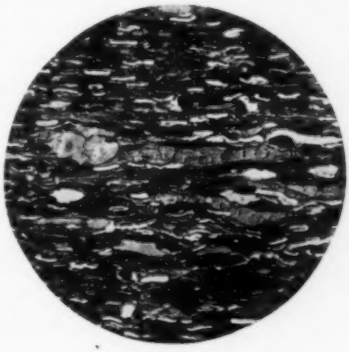

FIG. 3

Fig. 3 shows the organization of Kentucky cannel. Scattered throughout the matrix are light bodies which are yellow in the coal itself. These represent spores. They are inclosed in a darker matrix which in some cases reveals lighter, somewhat undulating or crinkled bands or particles. These structures are brown in color in the coal and represent the remains of wood. A large stripe of this kind runs nearly across the illustration. Cannel owes its highly bituminous character to the presence of large quantities of spores, just as is the case with oilshales and tasmanite. Since the spore material is less pure than in the former types of coals, the bituminous matter is less and the distillate of petroleum is correspondingly reduced in amount.

[1] "The Nature of Some Supposed Algal Coals," *Am. Acad. Arts and Sci.*, XLVI (December, 1910).

It is universally admitted that all three types of coal shown in the illustrations are formed as a result of water deposit. It will be convenient at this stage to consider rather rare types of coal which show considerable evidence of being derived from ancient peat beds. Coals of this organization represent old swamps skirting the sea and correspond, with certain necessary allowances made for the difference of vegetation in the Paleozoic, to our existing tidal mangrove estuaries. They are usually designated on this account as paralic (*paralisch* of Naumann) coals. In some coals of this type from Great Britain, Westphalia, and the Donetz coal field of Russia

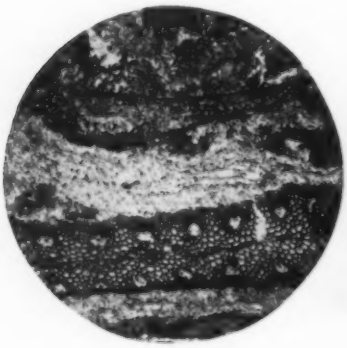

FIG. 4

FIG. 5

concretions have been found known as coal balls. A very good account of these structures, particularly for the English examples, was published, not long since, in the *Philosophical Transactions of the Royal Society of London*.[1] Our Fig. 4 shows the structure of a coal ball from the Westphalian coal field in Germany, which I owe to the courtesy of the Geologische Landesanstalt of Prussia. In the lower part of the figure is the crushed stem of a young calamite and the rest of the area is made up of less recognizable remains. Fig. 5 illustrates the appearance of the coal adhering to the outside of the same coal ball. It has been shown clearly by

[1] Stopes and Watson, "On the Present Distribution and Origin of the Calcareous Concretions in Coal Seams, Known as 'Coal Balls,'" *Phil. Trans. Roy. Soc. London*, Series B, Vol. CC, 167–218.

Stopes and Watson that true coal balls are formed *in situ* in the coal by local impregnation of the original peaty substance with lime or magnesium carbonate or both. The mineralized portion of the peat retains its structure, while that which has not been impregnated is completely devoid of definite organization when transformed into coal. If all coals were derived from ordinary peat they would present the same homogeneous organization as shown in our Fig. 5, since wood and similar formations have their structure obliterated when transformed into coal. In this respect peaty deposits present a marked contrast to the lacustrine mucks which have been the forerunners of cannels and oilshales. The spores and similar cutinized structures are the only remains of plants, which in general do not become obliterated in organization when passing into coal. Only petrification can save ordinary peat in the long run from the complete obliteration of its original vegetable constituents.

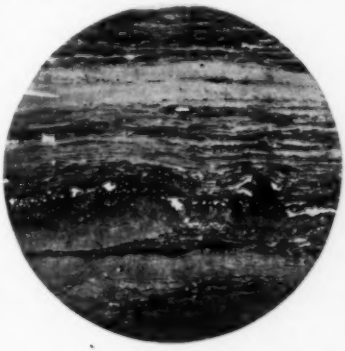

FIG. 6

It is now possible to consider with advantage the commoner types of coal, those which occur in greatest abundance in all parts of the world where coal deposits exist. Fig. 6 illustrates a coal of this ordinary bituminous type from Illinois. It is at once clear that the structure is not homogeneous as in the Westphalian coal shown in Fig. 5. Running across the figure is a dark band of "mother of coal" or mineral charcoal. This represents wood which was charred by fire before it entered into the substance of the coal. Mother of coal, inappropriately so called, represents the only woody constituent of ordinary coals which retains its structure. Very often the woody elements are in a perfect condition of preservation and the nature of the trees which produced them can be diagnosed. In addition to the dark band of mineral charcoal or mother of coal, there are other narrower dark stripes in the coal, as well as lighter-hued more homogeneous bands. The latter correspond to highly

modified wood. The nature of the others can best be understood from Fig. 7. This represents a portion of the last figure, much more highly magnified. The dark stripes are now seen to contain numbers of very light-colored bodies or spores.

Fig. 8 shows the organization of a very highly bituminous coal from Kentucky. The crenulated bands corresponding to layers of modified lignitic substance stand out very clearly in this illustration. Between the woody or lignitoid zones are darker stripes variegated with light linear bodies. The latter are compressed

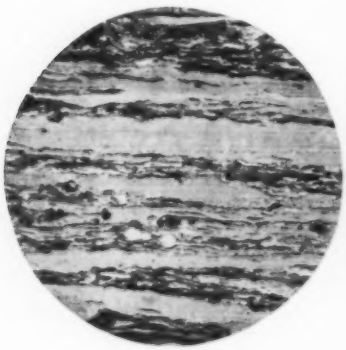

FIG. 7

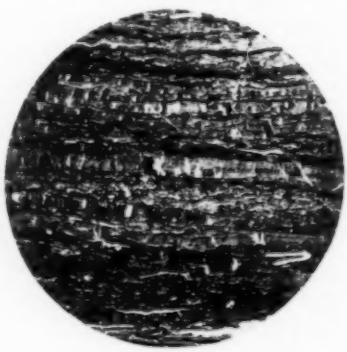

FIG. 8

spores. Fig. 9 shows a part of the foregoing highly magnified, and the canneloid nature of the darker bands alternating with the lignitoid layers can now be clearly ascertained.

Further examples of coals may now be considered. Fig. 10 shows the structure of a bituminous coal from European Russia. Clearly it is largely composed of spores. Through the courtesy of M. Zalessky of the Comité Géologique of St. Petersburg, I have had the opportunity of examining a considerable number of coals from European as well as Asiatic Russia, with similar results as regards organization (except of course the coals of paralic origin). Fig. 11 reveals the structure of non-coking bituminous coal from Indiana. The conditions presented are the same as in the case of the Illinois coal, with the exception that the spore material is very scanty, as indeed is the case with all lean bituminous coals, in

contrast to fat coking and gas coals. Fig. 12 illustrates the organization of a bituminous coal from St. Caterina, South America. The spores and lignitoid substances are as characteristically present as in the other cases. Fig. 13 shows the structure of a high-grade steam coal from Virginia. Here, as in the other cases described for bituminous coals, spores as well as lignitoid substance are found. As a final illustration, in Fig. 14 is shown a coal from Lancashire in England. The narrow stripes of lignitoid and the abundant light-hued spores can readily be discerned.

FIG. 9

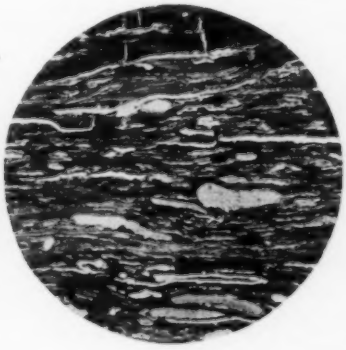

FIG. 10

Through the courtesy of the Director of the United States Geological Survey and Dr. David White, Chief Geologist, I have had the opportunity of examining nearly two hundred coals from various states of the Union and from Alaska. The results of investigation so far as bituminous coals are concerned, from whatever geological horizon obtained, showed in all instances the presence of a greater or less amount of spore material. Through the kindness of the Director of the Geological Survey of Canada, I have been able to examine into the structure of the Mesozoic coals of the Canadian West and Vancouver Island, as well as the coking and non-coking Carboniferous and Permian coals of New Brunswick, Nova Scotia, and Cape Breton Island. The results here were similar to those obtained in American coals. The coal deposits of England and Scotland have also supplied numerous and varied

samples, which in all cases led to the same conclusion: namely, that spores are a practically unfailing constituent of ordinary coal. The coals of Scania (Triassic) in Sweden have yielded results in harmony with those already described for other countries and continents. Of oriental coals I have, through the courtesy of the United States Bureau of Mines, been able to examine several from Japan and China. These revealed the same unfailing spore content characteristic of other material examined. I have also examined a number of coals from both the Queensland and New South Wales

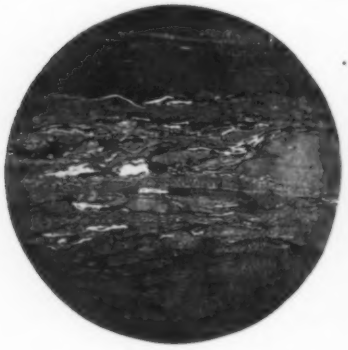

FIG. 11

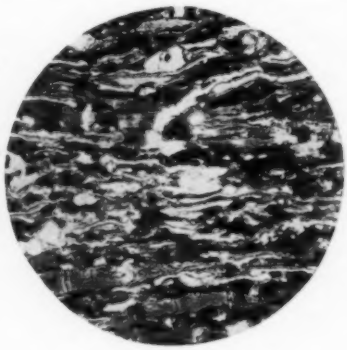

FIG. 12

coal fields of Australia, which in some cases showed a very high spore content and in all instances contained these bodies. Coals from Venezuela, Chile, Brazil, and Patagonia of various geological periods yielded similar results on microscopic investigation.

The almost universal presence of quantities of spores in coals is a phenomenon not without significance in connection with our views in regard to the origin of coal substance. In the case of cannels, oilshales, and similar coals, the high spore content is interpreted on all hands as clear evidence of their formation in open water. In contrast, however, to the views held in regard to the origin of cannels and coals of similar organization are those entertained in regard to the conditions of formation of ordinary bituminous coals. These coals are regarded by the majority of geologists and paleobotanists, both in Europe and in this country,

as of terrestrial origin. The reasons for this belief are drawn mainly from the strata related to the coal beds, but it is somewhat generally admitted that the character of the underclay or seatearth of a coal bed is no more final proof of its condition of origin than the cover of a book is necessarily convincing evidence as to the age and nature of its contents. It becomes clear, as a result of the microscopic examination of coals at large, that they cannot in general be derived from ordinary peat, as they do not show the structure of coals which by inclosed petrifications are known to be of peaty deriva-

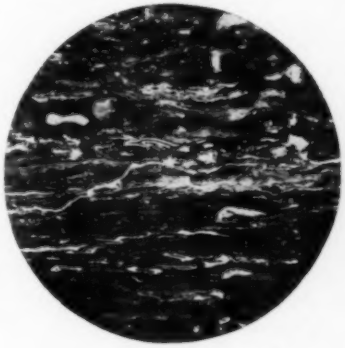

FIG. 13

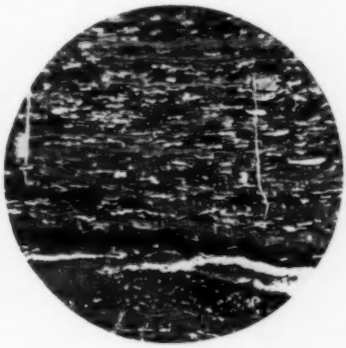

FIG. 14

tion. The paralic or old seaboard coals of Great Britain and parts of Continental Europe have a homogeneous structure, as has been shown above in the case of Westphalian coals. This homogeneity is not at all due to opacity of the thin sections, because even when quite translucent, as when prepared by the improved methods devised for the sectioning of coal, preliminarily described in the article on "Supposed Algal Coals," cited earlier in the present communication, they show no clear evidence of structure, except so far as they contain fragments of carbonized wood, a condition not uncommon in the paralic coals of British origin.

Since it is generally admitted that coals containing large quantities of spores are of aquatic origin, that is, are deposited in open water, the question arises naturally, in view of the conditions described above for ordinary bituminous coals, whether they are

not also laid down in open lakes, lagoons, or tranquil estuaries. There seems to be little doubt that this is the case, because not only do they show to a large extent the organization of cannels but they often pass imperceptibly into coals of this type. Moreover, an equally cogent argument is supplied by the examination of lacustrine muck of the present age. In the greatest depths of our modern lakes, which are usually of glacial origin, one ordinarily finds quantities of diatomaceous tests, or, if the region be a limestone one, a thicker or thinner stratum of a white limy deposit, containing the remains of stoneworts or Characeae. Above the basal deposits occur strata extremely rich in the pollen of conifers and certain catkin-bearing plants, such as the willow, the alder, and the birch. As the water grows shallower by accumulation of organic mud, we begin to find remains of water-lilies and other aquatics mingled with pollen. Then come layers of coarser remains of land plants, twigs, leaves, bits of wood, etc., swept by rain and winds into the lake and always more or less intermingled with a decreasing proportion of spores, until the organic silting of the waters results in the emergence of land, which if not characterizable as dry, still is able to support the growth of land plants. With the use of a peat prober of the type devised by Dr. C. A. Davis, of the United States Bureau of Mines, it is possible to recognize, by probing the depths of the bogs which vegetate on the bosoms of filled lakes, the general order of deposits outlined in the foregoing sentences. Ordinarily the depth of one of these obliterated lakes is not more than ten to twenty feet, so that we have the whole interval from the ice age to the present for the accumulation of the filling material. The estimates of the remoteness of the last glaciation vary from 25,000 years to four times that length of time. Even accepting the smallest estimate, the interval required to fill a lake ten feet in depth is great enough to call for a deposit of less than one foot of material in a thousand years, or not more than one-tenth of a foot in a century. This extremely slow rate of deposition relieves us from having to answer a stock objection to the possibility of the lacustrine formation of the raw materials of coal. It has often been pointed out that a rate of erosion necessary to fill up a large body of water in a relatively brief interval,

with organic materials, would be torrential in its action. As a matter of fact, judging from actual conditions, given abundance of time, almost unlimited accumulation of vegetable remains in water, without any appreciable admixture of mineral matter, can be accounted for, particularly since vegetable substance once permanently covered by water is practically imperishable.

A very serious objection to the peat hypothesis of the origin of coal lies in the observed fact that peat bogs are not found in the parts of our present world which in their climatic warmth correspond to the probable conditions obtaining during the great coal age, the Carboniferous. Vegetable matter not continuously covered by water quickly disappears in tropical climates. True, Potonié has called attention, in his truly monumental work[1] on peat and similar formations, to the existence of what he considers to be a true peat bog in central Sumatra. The illustrations given show clearly, however, that there is present a filled body of water with trees growing upon its scarcely elevated surface. The organic material, moreover, as figured in Potonié's work, contains large quantities of pollen, thus showing its essentially open-water origin. There can be no reasonable doubt that it was as impossible for vegetable matter to accumulate on land, even on wet land, in the Carboniferous and later periods in the Mesozoic and Tertiary, as it is in subtropical and tropical climates at the present time.

We are then apparently brought to the conclusion, both from the conditions of peat formation in the present age on the one hand, and from the actual organization of the commonest and most abundant coals of every geological age and in all parts of our earth, on the other, that the raw materials of coal were heaped up, not as the result of the growth of successive generations of plants on the prostrate and persistent bodies of those already fallen, but as the age-long gradual accumulation of vegetable matter in open water. In other words, coal is not a compost heap but a sedimentary deposit. Striking as are our actual peat bogs in temperate climates, in reality they throw no light on the accumulations of vegetable matter in past ages, which have been preserved to us in the form of coal. The less conspicuous accumulations of vegetable matter

[1] *Die Recenten Kaustobiolithe u. ihre Lagerstaetten*, Berlin, 1908–12.

in the bottoms of our existing lakes afford the real elucidation of the mode of formation of coal beds. As in our actual bodies of water, which accumulate vegetable deposits, the nature of the material laid down varies with the depth, tranquillity of the water, and other conditions, so the nature of coals derived from similar formations of past ages varies in composition. Where the spore material is more abundant, the result is a cannel or an oilshale. Where it is still plentiful but not superabundant, we have coking and gas coals as a product. Where poverty is manifest in the spore content, lean or ordinary bituminous coals are formed. The processes of devolatilization leading to the formation of anthracites and similar high-grade coals will not be considered in the present connection.

CONTRIBUTIONS TO THE PETROGRAPHY OF JAVA AND CELEBES

JOSEPH P. IDDINGS AND EDWARD W. MORLEY

In a short visit to Java and Celebes in 1910 one of the authors visited several localities in Java, the rocks of which have been described by Verbeek,[1] and also the region of the Pic de Maros in Celebes, from which rocks were collected by Paul F. Sarasin and subsequently were described by C. Schmidt.[2] Part of the material collected on this visit has been analyzed chemically by the other author of this paper, and the analyses have been published, for the most part, without special description in the second volume of *Igneous Rocks* recently printed.[3] It is the purpose of this paper to call attention more specifically to the characters of the rocks analyzed, and to point out certain chemical and mineral relationships between the leucitic lavas of Mt. Mouriah in Java and the shonkinites and nephelite syenites in the vicinity of the Pic de Maros in Celebes.

Mt. Mouriah in the Diapara Residency, northeast of Semarang, on the north coast of Java has been described by Verbeek as an extinct volcano, 1595 m. high, which has undergone extensive erosion but still exhibits evidences of two large circular craters. Associated with it are two smaller volcanoes of similar character, Paliaïan and Tülering. The rocks of these mountains are exclusively leucitic, but some varieties are poor in leucite. Other leucitic lavas occur in the small volcano Lourous, and the larger, much eroded volcano Ringgit, in Besouki Residency in Eastern Java. Leucitic rock, together with phonolites, also occurs on the island

[1] R. D. M. Verbeek and R. Fennema, *Java et Madoura*, Amsterdam, 1896.

[2] P. and F. Sarasin, *Insel Celebes; Anhang, Untersuchung einiger Gesteinssuiten.* Wiesbaden: C. Schmidt, 1901.

[3] J. P. Iddings, *Igneous Rocks*, II. New York, 1913.

Bawéan, between Java and Borneo. Verbeek states that Mt. Mouriah is in large part tuffs and breccia with some flows of massive lava. He describes the rocks as chiefly leucite tephrites and leucitites with small amounts of feldspar in the groundmass; there being all gradations between these varieties. Olivine-bearing varieties are much fewer. In some of the rocks there are phenocrysts of leucite 5–10 mm. in diameter, and in exceptional instances 15 mm. The groundmass of these rocks is in most instances dark gray to black, dense and aphanitic, less often porous.

Two of the localities on Mt. Mouriah mentioned in Verbeek's description were visited in 1910: one was the stream Kali Gillinan, near the village Masin, on the south slope of the mountain above Bareng; the other locality was the stream Kali Sekatak, below the village Ragou, above Petjangaän, at the west base of the mountain. The first stream has a narrow channel at the place visited, and washes great bowlders of lava, and has short beaches of smaller bowlders and gravel. The second stream is much larger, flows in more open country below Ragou, and has long reaches of gravel and bowlders. In both places the bowlders represented great varieties of leucitic rocks which were mostly dense and compact and extremely fresh and unaltered by weathering, leucite crystals at the surface of the bowlders being transparent, or only slightly whitened in some instances, but completely altered in others. However, when the rocks are broken the interior portions usually appear to be very fresh, which proves to be the case when their sections are studied microscopically. These leucitic rocks, although considered by Verbeek to be possibly of late Tertiary age, are as fresh and as well preserved as modern lavas, or as many Tertiary lavas in the arid regions of Western America. In places where they have been covered by soil and vegetation for long periods of time they are completely decomposed for a short distance from the rock surface, as Mohr has shown to be the case with andesitic rocks in other parts of Java. Of 37 specimens collected from various bowlders at the two localities named, 8 varieties have been analyzed chemically, the analyses and norms being given in Table I, together with analyses of lavas from two active craters in other parts of Java; a short petrographic description of each follows.

TABLE I

Analyses of Lavas from Java

	1	2	3	4	5	6	7	8	9	10
SiO_2	51.85	50.18	48.32	48.66	47.73	46.54	46.60	45.03	55.42	51.12
Al_2O_3	19.08	17.82	17.81	17.69	17.93	15.95	16.73	16.59	17.39	19.59
Fe_2O_3	4.25	4.04	4.65	4.66	4.47	5.24	4.17	4.55	1.56	2.86
FeO	2.69	3.89	4.62	4.40	4.58	5.51	4.78	6.37	6.82	6.53
MgO	1.48	2.88	3.37	3.03	4.27	4.70	4.65	3.95	3.28	4.47
CaO	5.81	7.19	9.15	6.43	9.59	10.09	10.82	11.09	7.57	9.54
Na_2O	4.46	3.29	3.14	3.93	3.62	2.28	2.62	3.53	2.41	3.11
K_2O	6.61	6.65	4.79	6.10	4.81	4.44	5.47	5.29	2.67	0.57
H_2O+	0.55	0.96	0.82	0.80	0.44	0.52	0.71	0.34	0.17	0.11
H_2O-	0.49	0.55	0.17	0.58	0.24	0.59	0.45	0.15	0.00	0.00
TiO_2	0.66	0.76	0.88	0.81	0.86	1.11	0.95	1.10	1.07	0.86
ZrO_2	0.00	N.p.	0.00	0.00	0.00	0.01	N.p.	0.00	0.00	0.00
CO_2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
P_2O_5	1.23	0.76	0.82	0.79	0.52	1.18	1.50	0.96	0.58	0.14
Cl	0.21	0.16	0.10	0.24	0.17	0.07	0.08	0.26	0.11	0.10
F	0.10	0.02	0.04	0.16	0.07	0.06	0.17	0.11	0.03	0.04
S	0.01	0.02	0.23	0.05	0.04	0.09	0.01	0.05	0.03	0.06
Cr_2O_3	0.00	N.p.	0.00	0.00	0.00	N.p.	N.p.	0.00	0.00	0.00
MnO	0.51	0.30	0.41	1.49	0.96	0.18	0.41	0.64	0.71	0.65
BaO	0.17	0.25	0.11	0.16	0.10	0.13	0.21	0.16	0.13	0.03
SrO	0.19	0.29	0.21	0.21	0.17	0.24	0.13	0.16	0.03	0.03
	100.40	100.01	99.64	100.19	100.57	99.53	100.46	100.33	99.98	99.81

Norms of the Lavas Analyzed

	1	2	3	4	5	6	7	8	9	10
Q	.....	.....	.....	.....	.....	.....	.....	.....	7.9	2.2
Or	38.9	39.5	28.4	36.1	28.4	26.1	28.4	14.5	16.1	3.3
Ab	18.3	7.9	11.0	8.9	3.7	5.8	.....	.....	19.9	25.7
An	13.3	14.2	20.3	13.3	18.9	20.3	17.5	15.3	28.9	38.1
Ne	9.7	10.8	8.5	12.5	13.9	7.4	11.9	14.8	.....	.....
Lc	.....	.....	.....	.....	.....	.....	3.5	13.1	.....	.....
Hl	0.4	.....	.....	0.4	0.2	.....	.....	0.5	0.1	0.1
Di	7.1	14.1	16.6	11.1	20.8	23.1	21.3	27.9	4.6	6.9
Hy	.....	.....	.....	.....	.....	.....	.....	.....	16.4	17.1
Ol	1.1	2.5	2.9	5.8	4.2	3.7	4.3	2.6	.....	.....
Mt	6.3	5.8	6.7	6.7	6.5	7.7	6.0	6.7	2.3	4.2
Il	1.4	1.5	1.7	1.5	1.7	2.1	1.8	2.1	2.1	1.7
Pr	.....	.....	0.4	.....	.....	.....	.....	.....	.....	.....
Ap	2.7	2.0	2.0	2.0	1.3	2.7	3.7	2.4	1.3	0.3

1. Vicoite, borolanose-monzonose, 'II. 5(6). 2. 3. Gillinan, near Masin. E. W. Morley.
2. Leucite tephrite, borolanose, II. '6. 2. '3. Near Ragou. E. W. Morley.
3. Vicoite, —shoshonose, II. 5(6). '3. 3. Near Ragou. E. W. Morley.
4. Orthoclase-bearing leucite tephrite, borolanose, II. '6. 2. 3. Gillinan. Near Masin. E. W. Morley.
5. Biotite vicoite, borolanose—, II. '6. (2)3. 3. Near Ragou. E. W. Morley.
6. Leucitophyre, kentallenose, 'III, 5. '3. 3. Gillinan, near Masin. E. W. Morley.
7. Leucite tephrite, ourose, (II) III. 6. '3. '3. Near Ragou. E. W. Morley.
8. Vicoite, cascadose, 'III. 7. 2'. 3. Near Ragou. E. W. Morley.
9. Glassy shoshonite, shoshonose, II. (4) 5. 3 (4). 3'. Bromo Crater. E. W. Morley.
10. Basalt, hessose, II. 5. 4. '3. Goentoer lava. E. W. Morley.

The rock whose analysis is No. 1 is a light-gray, aphanitic variety from Kali Gillinan near Masin, which contains rather numerous large phenocrysts of leucite, ranging in size from a diameter of 10 mm. to microscopic dimensions. In thin section they exhibit characteristic polysynthetic twinning, and the index of refraction has been determined by Dr. F. E. Wright to be 1.507 for sodium light. Their chemical composition is shown by the following analysis by Morley:

SiO_2	54.97
Al_2O_3	22.21
K_2O	19.98
Na_2O	0.81
Fe_2O_3	0.61
MgO	0.26
CaO	0.40
H_2O-	0.08
H_2O+	0.56
	99.97

The groundmass is minophyric and dopatic with abundant small phenocrysts of leucite, augite, and some minute feldspars. In thin section it is seen to consist of small phenocrysts of euhedral leucite, zonal augite, and numerous zonal crystals of calcic andesine or labradorite in a holocrystalline groundmass composed of leucite, prismoids of greenish augite, anhedrons of magnetite, with prismoid plagioclase and anhedral orthoclase, some of which form narrow shells around the plagioclase, as in some shoshonites. The calculated norm shows 38.9 orthoclase, 18.3 albite, and 9.7 nephelite, whereas the mode, or actual mineral composition of the rock, shows that no nephelite crystallized from the magma, but considerable albite, which appears in the lime-soda feldspar. Readjusted on this basis the rock might contain about 1.1 orthoclase, 36.2 albite, 29.7 leucite, and no nephelite. Owing to the smallness of the crystals in the groundmass an actual measurement of the mode of the rock cannot be made without great difficulty. The rock may be called a vicoite, which is equivalent to a leucite shoshonite.

The rock of analysis No. 2 is medium gray, very similar to that of No. 1, and occurs on Kali Sekatak near Ragou. The phenocrysts of leucite range in size from 10 mm. downward and in places are

partly separated from the matrix by small spaces or cracks, which indicate that the magma was so stiff just before it solidified that it pulled apart through stretching. In thin section there are small phenocrysts of leucite, augite, magnetite, and reddish-brown biotite, which has an outer zone with weaker absorption than the central part, and in some instances has a margin filled with inclusions. The groundmass consists of leucite, slender prisms of lime-soda feldspar, minute prisms and anhedrons of augite, and magnetite. The chemical analysis and norm show that the rock is a little more femic than the variety first described, No. 1, and that it contains slightly less soda and normative albite. In place of 39.5 per cent of normative orthoclase and 10.8 of normative nephelite, there has crystallized abundant leucite and no nephelite. The rock is leucite tephrite.

The rock of analysis No. 3 is gray, dense, vitreous to subvitreous, and aphanitic, and is from Kali Sekatak. It is minophysic and dopatic, with abundant small phenocrysts of augite. In thin section the groundmass is seen to be holocrystalline and to consist of lime-soda feldspar surrounded by alkalic feldspar, besides anhedral crystals of alkalic feldspar and some leucite, with minute crystals of augite and magnetite. The chemical analysis and norm show this to be a still more femic variety with less alkalies. No nephelite or olivine is recognizable in the rock, and none was observed in Nos. 1 and 2. The rock may be classed as a vicoite, or an orthoclase-bearing leucite tephrite.

The rock of analysis No. 4 is light gray, and aphanitic, from Kali Gillinan. It is dopatic, with small phenocrysts of augite, but no megascopic crystals of leucite or feldspar. In thin section it is seen to contain numerous small phenocrysts of augite, leucite, and very small magnetites, in a holocrystalline matrix composed of prismoid lime-soda feldspar, anhedral orthoclase, leucite, and augite. The chemical analysis and norm are much like those of No. 2, which, however, is characterized by large phenocrysts of leucite. The rock is a variety of leucite tephrite with orthoclase, related to vicoite.

The rock of analysis No. 5 is medium gray, aphanitic, and very porous, from Kali Sekatak, and has some large phenocrysts of

biotite, ranging downward to microscopic crystals, also phenocrysts of augite, but none of leucite or feldspar. In thin section there are abundant small phenocrysts of zonal pleochroic augite, considerable brown mica, zonal lime-soda feldspar, and magnetite, with relatively large crystals of colorless apatite, and a few anhedral, brownish-green hornblendes. There is some ill-defined colorless mineral which may be in part orthoclase, in part leucite. No olivine is to be seen. The chemical composition is very similar to that of No. 3. The norm shows it to be slightly more femic, with more normative nephelite and olivine, and the same amount of normative orthoclase, but the crystallization of abundant biotite accounts for the non-appearance of olivine, and the small amount of leucite without nephelite in the mode. The rock might be classed as a variety of biotite vicoite.

The rock of analysis No. 6 is dark gray and dense, from Kali Gillinan. It is minophyric, sempatic, with comparatively few large phenocrysts of leucite, and abundant small phenocrysts of augite and leucite. In thin section there are abundant leucites, as phenocrysts, as clusters of crystals, and as microscopic crystals in the groundmass. Some clusters of leucites surround augite, others inclose plagioclase, augite, and magnetite. The phenocrysts of augite have pronounced zonal structure; there is a small amount of euhedral olivine. Small crystals of magnetite in some instances have very irregular outlines owing to pockets of groundmass and partly inclosed minute crystals of augite and plagioclase; the outline of the magnetite being rounded in places, as is the case with quartzes having similar partial inclusions. The rounded forms are clearly forms of growth and not of solution, as sometimes suggested. The holocrystalline groundmass contains considerable zonal calcic plagioclase, besides minute crystals of the other mineral constituents of the rock. The chemical analysis and norm show that this variety is more femic than the preceding ones, and that it is richer in normative anorthite. Normative orthoclase and nephelite are represented by modal leucite and by albite in the lime-soda feldspar. Olivine is modal as well as normative. The rock may be called a leucitophyre or leucite basanite.

The rock of analysis No. 7 is gray, dense, and aphanitic with numerous pores, and is found in Kali Sekatak. It has abundant

small phenocrysts of augite, which in thin section are seen to be zonal. The groundmass consists of abundant small leucites with an interstitial matrix composed of augite, magnetite, and minute prismoids of plagioclase. The chemical analysis and norm are very similar to those of No. 5, but the mode differs in having much leucite and no biotite. The rock is a leucite tephrite.

The rock of analysis No. 8 is gray, dense, aphanitic, and non-porphyritic, from Kali Sekatak. In thin section it is seen to be holocrystalline, and to consist of prisms of augite with some magnetite, and many leucites with anhedral orthoclase and anhedral alkalic plagioclase, or lime-soda feldspar surrounded by orthoclase. From the chemical analysis and norm it is seen to be the most femic variety from this region that has been analyzed. There are 13 per cent of normative leucite, and nearly 15 of normative nephelite which does not appear as modal nephelite, but must be represented by albite molecules, and by a greater amount of leucite than appears in the norm. The rock may be considered a variety of non-porphyritic vicoite.

While no crystals of nephelite have been recognized in any of the thin sections of these rocks, some of the specimens collected have numerous cavities with small white hexagonal crystals with basal planes, which appear to be altered nephelite. In other specimens there are cavities containing brilliant square prismatic crystals terminated by pyramidal planes over the edges of the prism, which have the index of refraction and habit of stilbite.

In a region where there are such highly potassic lavas as those of Mt. Mouriah it is to be expected that the lavas of more recent date should contain notable amounts of potash. Through the kindness of Dr. Verbeek a study was made of the thin sections of rocks collected by him and deposited in the Bureau of Mines, in Batavia, in order to learn whether orthoclase-bearing varieties of the andesitic lavas could be found. The collection contains few holocrystalline rocks which show orthoclase borders around prismoids of plagioclase, which might be called shoshonites or trachy-andesites. In most cases studied the rocks have a glassy matrix which might contain whatever orthoclase molecules were present in excess of those entering plagioclase crystals. However, the strongly porphyritic glassy lava which occurs in ejected blocks

at the cinder cone of the Bromo volcano in the old Tengger crater, in Eastern Java, has been analyzed chemically with the result shown in analysis No. 9, and proves to be a glassy variety of shoshonite, which shows no orthoclase, or other potassic mineral, in thin section. The dull glassy matrix contains abundant large phenocrysts of calcic plagioclase, having an index of refraction, β, which is 1.560, corresponding to labradorite, $Ab_1An_{1.2}$, and much fewer of brown vitreous augite. In thin section the groundmass is seen to consist of brown glass full of prismoid plagioclase, equant anhedral augite, and magnetite, with phenocrysts of labradorite and a few of augite, olivine, and magnetite.

The recent basaltic lava of Goentoer volcano has been analyzed also, and found to be hessose, with low potash, analysis No. 10. The lava is dark gray, aphanitic, and porous; is minophysic with few large phenocrysts of glassy feldspar with $\beta = 1.575$, which are anorthite, Ab_1An_{10}, and many small ones of less calcic feldspar and glassy yellow olivine. The groundmass contains a small amount of globulitic glass base, between abundant microlites of labradorite and fewer of augite, olivine, and magnetite.

The Pic de Maros is a mountain of igneous rocks covered with vegetation, which forms the southwestern extremity of a short ridge, situated between Maros and Tjamba, north of Makassar, in Celebes. Its rocks are exposed in place in a few localities, but may be seen in great variety in bowlders in the stream Gentungen, in the vicinity of Beleangin, and in loose material in drainage channels at the north base of the mountain. From the last two localities numerous specimens were collected by P. and F. Sarasin and afterward were described by C. Schmidt. In a hurried visit made by one of the authors of this paper some additional observations were made of rocks in place along the road on the west and south flank of the mountain, and some other varieties of rock were collected from the stream Gentungen.

About 5 miles up the road from the rest house, Patinoean, toward Tjamba there are large rounded exposures of massive shonkinite, which is exposed again a mile farther on the same road, and at other places. The rocks are dark colored, medium grained, and are almost perfectly fresh on the rough weathered surface. The

freshness of these rocks along the roadside where not covered by soil and vegetation is extremely interesting and was unexpected, since the rocks are intrusive bodies which have been uncovered by gradual erosion, and are not recent lava flows. They consist of abundant crystals of black mica, the largest 4 mm. in diameter, with euhedral prisms of augite, the largest being 6 mm. long, besides nearly equal amounts of glassy feldspar, some of which is prismoid, while others are anhedral. In thin sections these rocks are seen to consist of nearly equal amounts of mafic minerals and feldspar, which are augite, much brown biotite, considerable magnetite and apatite; the feldspar is almost wholly orthoclase in prismoid sections, with very little lime-soda feldspar. One section shows a little interstitial quartz.

Similar varieties of shonkinite occur as bowlders in the stream Gentungen. One variety at this locality is very similar in general appearance to those just described, but is richer in mafic minerals. It is medium grained, in thin section it might be called coarse grained, and consists of much augite and brown biotite, which crystallized almost synchronously and inclose much colorless apatite, and also magnetite. There is also a very small amount of greenish hornblende which has crystallized around augite. The subordinate felsic components of the rock are chiefly orthoclase, or microperthite, which is slightly cloudy, besides some very transparent calcic plagioclase, and a small amount of interstitial isotropic mineral which is probably sodalite. The chemical composition of this variety of shonkinite is shown by analysis No. 16, and its place in the Quantitative System of Classification is found to be in division III. 6. 3. 2, ottajanose, more exactly its symbol is III. 6. (2) 3. 2. The norm contains over 10 per cent of lenads and 12 per cent of olivine which do not appear in the mode, owing to the large amount of biotite which crystallized from the magma. This variety of shonkinite has been called marosite.

Still another variety of shonkinite found in bowlders in Gentungen is characterized by large poikilitic micas, 20–30 mm. in diameter, which lie in all possible positions in the rock. This variety grades into one in which the micas are not poikilitic, but yield brilliant cleavage plates 10–15 mm. in diameter. In thin

section these two varieties of shonkinite show much mica and augite, with considerable apatite and magnetite. The inclusions in the poikilitic mica are augite and plagioclase. There are large poikilitic crystals of orthoclase, and many small crystals of all the constituent minerals of the rock. The chemical composition of this variety is shown in analysis No. 15, which is not very different from No. 16. Owing to somewhat more calcic feldspar in the norm, which also appears in the mode, the rock belongs in kentallenose. III. 5. 3. 3; more exactly it is III. 5 (6). 3 (4). 3, so that it may be called a biotite kentallenite rather than biotite shonkinite.

Another rock in the Gentungen bears a striking resemblance to the pseudoleucite shonkinite, or fergusite, from Montana, described by Pirsson.[1] It has a dark gray, very fine-grained matrix, with abundant equant, whitish pseudoleucites, irregularly scattered and in clusters, the individual spots being about 3 mm. in diameter; a few, 6 mm. There are also some small poikilitic plates of

TABLE II

CHEMICAL ANALYSES OF ROCKS FROM CELEBES, BORNEO, AND SUMATRA

	11	12	13	14	15	16	17	18	19	20
SiO_2	58.79	58.61	56.31	46.08	45.26	43.98	46.04	46.05	61.91	53.75
Al_2O_3	19.55	21.62	21.69	20.40	15.70	12.28	12.40	14.88	16.26	17.06
Fe_2O_3	1.82	1.16	1.20	2.12	2.44	3.49	3.54	4.22	2.45	4.18
FeO	1.43	0.79	0.97	3.27	6.16	7.70	5.58	5.78	3.96	5.50
MgO	0.74	0.16	0.54	6.30	8.28	8.00	12.60	5.98	1.81	4.07
CaO	2.37	1.71	1.88	8.48	11.95	11.19	8.38	13.47	4.35	7.72
Na_2O	4.21	6.60	5.56	2.07	1.73	1.33	1.62	1.41	4.40	3.33
K_2O	8.69	6.82	9.17	6.72	3.42	5.06	4.87	2.56	3.04	1.37
H_2O+	1.05	1.42	1.13	1.70	1.12	1.61	3.55	3.01	0.18	0.50
H_2O-	0.06	0.19	0.00	0.06	0.29	0.12	.....	0.52	0.10	0.39
TiO_2	0.54	0.17	0.41	1.39	1.66	2.24	2.20	0.93	0.79	0.88
ZrO_2	0.00	0.01	0.00	0.00	0.01	0.00	.....	0.00	0.00	0.00
CO_2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
P_2O_5	0.11	0.04	0.13	1.19	0.90	1.81	.....	0.59	0.40	0.25
Cl	0.12	0.07	0.28	0.10	0.25	0.12	.....	0.09	0.13	0.11
F	0.03	0.01	0.03	0.09	0.08	0.15	.....	0.03	0.04	0.06
S	0.02	Tr.	0.17	0.06	0.05	0.10	.....	0.04	0.05	0.06
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	.....	0.00	0.00	0.00
MnO	0.40	0.40	0.16	0.19	0.34	0.51	Tr.	0.21	0.20	0.50
BaO	0.08	0.01	0.05	0.11	0.10	0.16	.....	0.06	0.02	0.02
SrO	0.12	0.02	0.04	0.07	0.06	0.12	.....	0.07	0.06	0.12
	100.13	99.81	99.72	100.40	99.80	99.97	100.78	99.90	100.15	99.87

[1] L. V. Pirsson, *U.S. Geol. Survey, Bull. 237*, 1905, p. 74.

NORMS OF THE ROCKS ANALYZED

	11	12	13	14	15	16	17	18	19	20
Q	.....	.....	.....	.....	.....	.....	.....	.....	13.3	6.8
Or	51.7	40.0	54.5	26.1	20.0	24.5	25.0	15.6	17.8	8.3
Ab	25.7	35.1	14.7	.....	3.1	.....	.....	9.4	36.2	27.3
An	8.6	8.3	8.1	26.7	26.4	12.8	12.2	26.4	16.4	28.1
Ne	5.4	11.1	16.5	9.4	4.8	5.9	7.4	1.4	.....	.....
Lc	.....	.....	.....	10.5	.....	4.4	3.1	.....	.....	.....
Hl	.....	.....	0.5	.....	0.5	.....	.....	.....	0.2	0.1
C	.....	0.4	.....	.....	.....	.....	.....	.....	.....	.....
Di	1.8	.....	0.5	6.6	22.0	24.7	23.0	29.5	2.1	7.0
Hy	.....	.....	.....	.....	.....	.....	.....	.....	7.7	12.9
Ol	1.5	1.0	0.9	10.5	12.5	11.9	17.3	4.9	.....	.....
Mt	2.6	1.9	1.9	3.0	3.5	5.1	5.1	6.0	3.7	6.0
Hm	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Il	1.1	0.3	0.8	2.7	3.2	4.3	4.3	1.8	1.5	1.7
Fl	.....	.....	.....	.....	.....	0.3	.....	.....	.....	.....
Ap	0.3	.....	0.3	2.7	2.0	4.4	.....	1.3	1.0	0.7

11. Trachyte, pulaskose, I'. 5. '2. '3. Gentungen, Pic de Maros. E. W. Morley.
12. Sodalite trachyte, laurvikose-pulaskose, I. 5 (6). (1) 2. 3 (4). Road at S. W. base of Pic de Maros. E. W. Morley.
13. Nephelite syenite, beemerose-procenose, I. '6. (1) 2. 3. Gentungen, Pic de Maros. E. W. Morley.
14. Fergusite, — II. 6. 3. 2'. Gentungen, Pic de Maros. E. W. Morley.
15. Biotite kentallenite, ourose-kentallenose, III. 5 (6), 3 (4). '3. Gentungen, Pic de Maros. E. W. Morley.
16. Marosite, kajanose-ottajanose, III. 6. (2) 3. 2. Gentungen, Pic de Maros. E. W. Morley.
17. Mica-leucite basalt, kajanose, III. 6. 2 (3). 2'. Oekoe Kajan, East Borneo. Pisani and Brouwer.
18. Absarokite, kentallenose—, III. 5.(3) 4. 3. Road at S.W. base of Pic de Maros. E. W. Morley
19. Andesitic pitchstone, dacose, 'II. 4'. 2.' '4. Simaboer, Mesapi, Sumatra. E. W. Morley.
20. Andesite, andose, II. '5. 3'. 4. Rau Rau, Mesapi, Sumatra. E. W. Morley.

brownish-black mica. In thin section the whitish spots are seen to be microscrystalline aggregations of anhedral alkalic feldspar, apparently orthoclase, and anhedral nephelite. The dark-colored matrix resolves itself into a complex of prismoid and anhedral lime-soda feldspar, augite, somewhat poikilitic biotite, magnetite, and olivine. In places around the areas of pseudoleucite there are clusters of minute anhedrons, having the refractive index of pyroxene, which border small crystals of plagioclase or partly replace them. The chemical composition of this rock is given by analysis No. 14, which belongs in II. 6. 3. 2, and is more calcic, so far as normative feldspars are concerned, than fergusose, II. 6. 1. 2. The rock is an equivalent of nephelite monzonite, but has the habit of fergusite.

Besides the shonkinitic rocks in this region there are various syenitic rocks grading into nephelite syenites and their aphanitic

phases, syenite porphyry, bostonite, and trachyte, and also phonolite, which is said to form the summit of the Pic de Maros. There are varieties intermediate between shonkinite and syenite with subordinate amounts of mafic minerals. A nephelite syenite from the Gentungen is light gray and medium grained, with tabular crystals of orthoclase and quite subordinate amounts of mafic minerals. In thin section the feldspar crystals are seen to have a diverse arrangement, and form the bulk of the rock, through which are scattered stout hexagonal prisms of nephelite about the same size as the crystals of aegirite augite, besides smaller amounts of biotite and brown hornblende, also paramorphs of hornblende and mica, and small crystals of sphene. The chemical composition of this rock is given in analysis No. 13, which is in procenose, its symbol being I. '6. (1) 2. 3.

There are porphyritic trachytes with tabular phenocrysts of glassy orthoclase, some of which are 40 mm. long and 5 mm. thick. A variety with smaller phenocrysts of orthoclase, 15 mm. long, has a bluish-gray aphanitic groundmass and small equant phenocrysts of mafic minerals. In thin section the groundmass is seen to consist of prismoids and anhedrons of orthoclase, with small amounts of sodic plagioclase, nephelite, and interstitial sodalite. The mafic minerals are greenish-brown hornblende having very irregular outline, in part poikilitic with orthoclase feldspar, also small anhedrons of green augite, and magnetite. Its chemical composition is shown by analysis No. 11, pulaskose I'. 5. '2. '3. Part of the normative anorthite enters the mafic minerals, and part must be involved in the alkalic feldspar, which must be sodic orthoclase, for no plagioclase feldspar is recognizable in thin section.

On the road from Patinoean to Tjamba, about 7 miles from Patinoean, there is an exposure of altered tuff containing blocks of massive, light-gray, minutely crystalline rock, with few small phenocrysts of glassy tabular feldspar. Under a lens it is seen to consist of subparallel tabular feldspar with abundant reddish spots. In thin section the rock is seen to be holocrystalline, with trachytoid fabric, composed of anhedral crystals of orthoclase, yielding prismoid sections, some of which show Carlsbad twinning.

Scattered through the whole are anhedral, interstitial crystals of isotropic mineral, probably sodalite. These are small amounts of pale-green augite, brown biotite, and magnetite. The rock is sodalite trachyte, or sodalite bostonite, approaching phonolite in composition. Its chemical composition is shown in analysis No. 12 and corresponds to a variety of pulaskose, I. 5 (6). (1) 2. 3 (4). The norm contains 11 per cent of nephelite and 8 of anorthite, but no lime-soda feldspar is recognizable in thin section. Other varieties of aphanitic, more or less porphyritic, trachytes occur on the north slope of the mountain east of the stream Gentungen, some of which contain small amounts of sodalite; others carry considerable biotite.

At the west base of the Pic de Maros there is a sheet of surface lava which is exposed at the Falls of Maros, or Bantinoeran, and also along the road farther south, about 3 miles east of Patinoean, where it is columnar, and is overlaid by limestone. The rock is coarsely porphyritic with abundant phenocrysts of black euhedral augite, the largest 7 mm. in diameter, and less numerous dark-brown glassy olivines, in a dark-gray aphanitic groundmass speckled with small white spots. In thin section the augite phenocrysts are brownish green, slightly pleochroic, and zonal, the central part being lighter colored than the margin. Olivine is abundant and there is much lime-soda feldspar in small phenocrysts, short prismoid and tabular; besides some prismoid orthoclase and zones of orthoclase surrounding plagioclase. There is a fine-grained matrix of the same kinds of minerals with magnetite and zeolitized feldspathoid mineral which may have been analcite, nephelite, or leucite. The rock is a variety of orthoclase basalt, or absarokite, whose chemical composition is shown by analysis No. 18, III. 5. (3) 4.3, a somewhat more calcic rock than kentallenose, which is III. 5. 3. 3.

A comparison of the analyses of rocks from Mt. Mouriah and the Pic de Maros shows that the leucitic rocks of the one and the shonkinitic rocks of the other locality are chemically similar. They are low in silica, high in potash, and relatively high in alumina and calcium oxide. This shows itself mineralogically in the prominence of leucite in the lavas of Mt. Mouriah, and of orthoclase and

biotite in the phanerocrystalline rocks of the Pic de Maros, while augite is a prominent constituent in both series. The striking contrast between the two groups of rocks is the crystallization of leucite in the lavas, and the absence of nephelite, without any considerable amount of orthoclase, which when present is a microscopic constituent of the groundmass, also the absence of biotite in most phases of the leucitic lavas, although in some varieties biotite and orthoclase have been crystallized at the expense of leucite. While in the intrusive rocks of the Pic de Maros there is no leucite, but considerable nephelite in some instances, abundant orthoclase and biotite, and an absence of noticeable amounts of lime-soda feldspar; in some rocks it is probably present molecularly in considerable amounts. These mineralogical contrasts must be due to differences in chemical equilibrium within chemically similar magmas, resulting from physical differences attending the crystallization of lavas in one case and of intruded magmas in the other. Such contrasts have been pointed out before, but never with so good an illustration.

A pseudoleucite kentallenite, or fergusite, occurs with the shonkinitic rocks in Celebes, the former leucites having been replaced by orthoclase and nephelite. Leucitic lavas occur in the neighborhood of the Pic de Maros, and in numerous other localities in southwestern Celebes,[1] and a mica-leucite basalt with very similar chemical composition to the highly mafic shonkinite, marosite, occurs in East-Central Borneo on the Oeloe Kajan.[2] Strongly potassic magmas yielding leucitic lavas, and biotite-orthoclase phanerites, with more or less nephelite, occur widely scattered from Eastern Java, through Southwestern Celebes, and have been found in East-Central Borneo, so that it is probable that other rocks of this kind will be found in the eastern part of Southern Borneo. The extent of the region in which these leucitic rocks are found, nearly 1,000 miles in length, is much greater than that of Central Italy, which is at present the best-known region of leucitic lavas.

[1] H. Bücking, *Sammlungen des geol. Reichs-Museum Leiden* (Leyden, 1902), pt. 7. 45, and 1904, pt. 8.

F. Rinne, *Zeitschr. d.d. geol. Gesellsch.*, LII (1900), 1.

[2] H. A. Brouwer, *Versl. Kon. Akad. Wetensch. Amsterdam*, 1909.

In addition to the rocks just described from Java and Celebes there are two from Sumatra that have been analyzed in order to learn whether earlier analyses of rocks from the same localities which showed relatively high alkalies were correct. One is a grayish-black pitchstone with many minute phenocrysts that occurs where the road crosses a stream in the village of Semaboer, on the south slope of Merapi volcano, in Central Sumatra. In thin section it is seen to consist of brown globulitic glass base crowded with microlites of prismoid feldspar, pyroxene, and magnetite, with scattered phenocrysts of calcic plagioclase and brown pyroxene. The chemical analysis No. 19 and the norm show that it is dacose, with normal composition for a dacitic andesite-pitchstone without visible modal quartz crystals.

The second rock from this region is dark greenish gray and aphanitic, with minute phenocrysts of feldspar and mafic minerals. It occurs in a small stream near the village of Rau Rau, at the east base of Merapi volcano. In thin section it is seen to be almost holocrystalline, with possibly a little pale-brown glass base between prismoids of plagioclase and smaller prismoids and anhedrons of pyroxene, with magnetite. There are abundant small phenocrysts of calcic plagioclase, fewer larger ones of pale augite, and numerous small olivines. The chemical analysis No. 20 and the norm show the rock is an andose with normal amounts of alkalies. It may be called an olivine-bearing pyroxene andesite.

TRIMERORHACHIS, A PERMIAN TEMNOSPONDYL AMPHIBIAN

S. W. WILLISTON
University of Chicago

No genus of vertebrates occurs so abundantly in the Permian deposits of Texas and Oklahoma—it is unknown elsewhere—as *Trimerorhachis* Cope. Almost always the remains are found in bone-beds as masses, more or less cemented together, of isolated and disturbed bones, often broken, sometimes waterworn, never in anatomical relation. Isolated specimens are not often found, and in such cases where parts of a single skeleton are associated they are more or less jumbled together. The clavicular girdle only is sometimes found closely associated with the skull, filling out more or less the interval between the mandibles posteriorly. In the Chicago collections there are probably parts of at least five hundred individuals. I have counted seventy-five isolated occipital condyles, nearly as many articular ends of the mandible, and scores each of humeri, femora, ilia, scapulae, clavicles, and epipodials, for the larger part fragmentary. Very often the bones are associated with disconnected bones of *Diplocaulus;* not rarely with teeth of *Diplodus* and dipnoans; and sometimes with the smaller disconnected bones of land reptiles. All of which go to prove that the various species of *Trimerorhachis* were purely aquatic animals, living probably in shallow waters near the shores.

Different writers have expressed the opinion, and I have shared it, that *Trimerorhachis* is the most generalized of our American temnospondyl amphibians. I am now about convinced that it is the most specialized, for the following reasons:

We have very good reason to believe that this and other groups of stegocephs were, by the beginning of Permian times, already very old. The origin of terrestrial amphibians surely dates from at least as early as late Devonian times and of land reptiles from early Pennsylvanian if not Mississippian times. There can

be little doubt that *Eosauravus*, from the Coal Measures of Linton, Ohio, is a real reptile; and Watson has recently figured[1] a femur from the Lower Carboniferous of Scotland that he believes to be of a true reptile, or at least of a "precocious" amphibian. I think that he is right.

FIG. 1.—Skull of *Trimerorhachis insignis* Cope. One-half natural size: *pm*, premaxilla; *na*, nasal; *p*, prefrontal; *pf*, postfrontal; *po*, postorbital; *it*, intertemporal; *pa*, parietal; *st*, supratemporal; *j*, jugal; *sq*, squamosal; *ds*, dermosupraoccipital; *t*, tabulare; *l*, lacrimal; *m*, maxilla; *qj*, quadratojugal; *sp*, splenial; *psp*, postsplenial; *an*, angular; *art*, articular.

Trimerorhachis was a purely aquatic amphibian, as its mode of occurrence indicates and as its structure demonstrates. The characters showing aquatic adaptation are found in the anterior position of the orbits and their direction upward; in the relatively

[1] *Geological Magazine* (1914), p. 347.

small size of the limbs and the attachment of the anterior pair almost at the angle of the mandible; in the shape of the humerus, very unlike that of the terrestrial types, with the planes of its extremities but slightly divergent and with strong muscular rugosities, as in the plesiosaurs and marine turtles, situated low down; in the absence of the adductor ridge on the femur; in the relatively very short epipodials, a certain indication in crawling reptiles of swimming habits; in the conspicuous lack of ossification at the ends of the long bones; in the almost certain chondrification of the mesopodials and pubes; in the short scapulae, utterly unlike those of terrestrial amphibians; in the structure of the clavicular girdle, so like that of *Diplocaulus* as to be almost indistinguishable at first sight; and in the certainly bare skin. Further evidence is scarcely needed.

It may be granted that the first amphibians were aquatic animals, perhaps as much so as is our modern *Necturus*, although of that I am not convinced. If then, *Trimerorhachis* is a generalized amphibian, it naturally follows that it has retained its primitive structure and habits from Devonian times; that its peculiar clavicular girdle is primitive, as also the unossified mesopodials and the relatively feeble ossification of the vertebrae, the very small size of the pleurocentra, etc. It necessarily follows that if the clavicular girdle is primitive, that of the stereospondyl amphibians of the Upper Trias is also, for the buckler-like structure in these, the last of the stegocephs, is much more pronounced. On the other hand, I believe that the clavicular bones in the direct line of the ancestry of the reptiles were never large and rugose, that they began as small dermal elements and continued so in those amphibians which gave origin to the reptiles.

The occipital condyle of *Trimerorhachis* is remarkably different from that of all other known American Permian amphibians, as will be seen by reference to the figures (Fig. 5, I, J, K), in that it is single and deeply cupped, fishlike. Granted that this a primitive character, and it may be, it does not necessarily disprove the argument I make that *Trimerorhachis* was descended from terrestrial forbears, that its aquatic characters are acquired, not hereditary. Watson urges that the primitive amphibians had a closed

palate, like that of the reptiles; *Trimerorhachis* has very wide parasphenoidal vacuities, though only a slender parasphenoid. Certainly the resemblances between *Trimerorhachis* and *Diplocaulus* in the eyes, clavicular girdle, and small limbs are adaptive, not genetic, for *Diplocaulus* is a holospondylous amphibian.

In the evolution of the feet we know that aquatic adaptation has frequently resulted in the more or less complete chondrification of the mesopodials. One need only to study the progressive evolution of the mosasaurian paddle to be convinced of this.[1] And the cetaceans are still better examples.

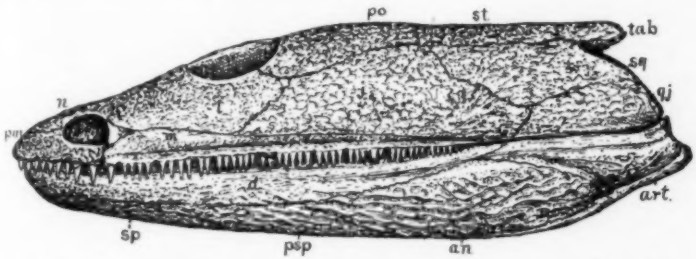

FIG. 2.—*Trimerorhachis insignis*, skull, from the side. Explanations as in Fig. 1

In the progressive adaptation of the tarsus to terrestrial life, there has been a continued loss of elements and a strengthening and closer articulation of those remaining, not only in the mammals, but in the reptiles as well. In the most primitive known tarsus, that of *Trematops*,[2] there are not less than thirteen ossified bones, four in the first row, four in the second, and five in the third. The early amphibian was a truly crawling animal, dragging its body over the surface of the ground. Its feet were directed outwardly, and the motion of the tarsus on the leg was chiefly lateral; the angle between the over-extended foot and the leg was always obtuse. In the evolution of the reptiles greater speed was attained by the elevation of the body from the ground in locomotion. No modern reptiles crawl, in the strict sense of the word, except the snakes and legless lizards—for the most part at least; many even

[1] Williston, *American Permian Vertebrates*, p. 45.

[2] Williston and Case, *Carnegie Publication, No. 181* (1913), p. 56.

rear themselves on the hind legs in running. In such locomotion the leg is brought more nearly at right angles with the plane of the plantigrade foot, and the result has been a closer union of the proximal bones of the tarsus, either with each other or with the leg bones. The earliest known reptile, from the Coal Measures of Ohio, had only two bones in the proximal row, the astragalus and calcaneum, and, even as early as the beginning of Permian times, the centralia and fifth tarsale had begun to disappear. In the elevation of the heel from the ground a further union of the proximal bones took place in some forms, *Pareiasaurus*, for instance, and some living lizards and turtles. In modern reptiles the foot is plantigrade. Among the first results of digitigradism was the closer union of the astragalus with the tibia, as seen in *Ornithomimus* and other bipedal dinosaurs, becoming more intimate in a more or less sutural union in *Rhamphorhynchus*, and the sutural obliteration in *Pteranodon* and birds, and the final union of the tarsalia with the metatarsals in the latter. In known reptiles the chief joint between the leg and foot is intratarsal, that is between the first and third rows. In the mammals it is between the tibia and the astragalus. One wonders how the change occurred in the ancestral reptiles.

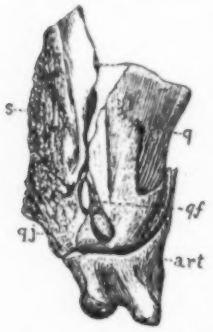

FIG. 3.—*Trimerorhachis*, part of skull, from behind: *q*, quadrate; *qf*, quadrate foramen; *art*, articular; *s*, squamosal; *qj*, quadratojugal. One-half natural size.

Not only has the vertical posture of the leg been the cause of the loss of tarsal bones, and of the change of the chief tarsal joint to the immediate end of the tibia, as in mammals, or its functional equivalent in the dinosaurs, ptderodactyls, and birds, but it has also been the cause, I believe, of the reduction of the phalanges in turtles, theriodonts, and mammals. In the most rectigrade posture of the lower leg and foot of all turtles, the land tortoises, but two phalanges remain in each toe. In the rectigrade Sauropoda no toe has, I believe, more than four phalanges; and the tarsal bones are much reduced.

Notwithstanding the abundant but disconnected material, I have been frustrated in the attempt to make out the complete anatomy of *Trimerorhachis*, and it will only be by the fortunate discovery of a connected skeleton that the tail, ribs, and feet will be made known. The figures of the skull herewith given are based chiefly upon three specimens. The most perfect of these, so far as form is concerned, is a solitary skull and clavicular girdle found by Mr. Miller in the same horizon as, and in the immediate vicinity

FIG. 4.—Clavicular girdle of *T. insignis*, from below; four-fifths natural size

of, the skeleton of *Seymouria* described by me in a previous paper. The specimen originally was perfect and undistorted, but weathering had carried away much of the thin roof, leaving the cast very smooth and complete. These parts have been completed from two other specimens of identical size and character, specimens collected in Texas nearly twenty years ago by Professor Case. The sutures separating the elements have been determined chiefly from these three specimens, aided by parts of several others, and I think can be relied upon. In their general courses and relations there is but little novelty in the figures. All of them, except the

more anterior ones, were first determined by Professor Case.[1] Dr. Huene completed our knowledge of the anterior ones, and Dr. Broom has corroborated the most of them. The most striking peculiarity of the skull is seen in the large size and posterior extension of the lacrimal.

The figure of the clavicular girdle is made from one of the numerous isolated specimens agreeing closely with that attached to the first-mentioned skull. Its comparison with that of *Cacops*[2]

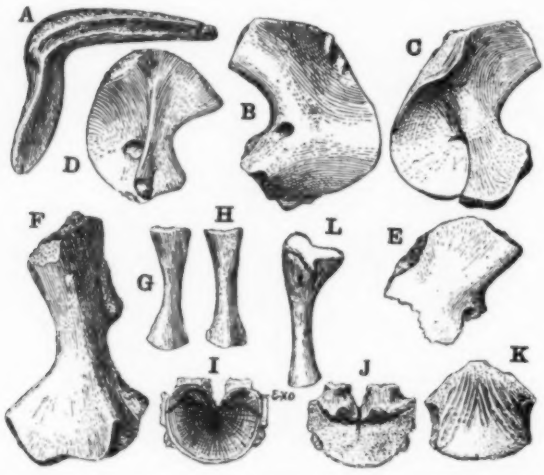

FIG. 5.—*Trimerorhachis*. *A*, right interclavicle, from behind; *B*, right scapula, from without; *C*, the same, from within; *D*, scapula of a smaller individual or species; *E*, fragment of another scapula; *F*, humerus; *G*, *H*, radii; *I*, occipital condyle from behind; *exo*, exoccipital; *J*, the same bone from in front; *K*, the same from below; *L*, ulna. All figures three-fourths natural size.

will show the extraordinary differences from the more terrestrial type of the contemporary temnospondyl amphibians. The scapula is also very peculiar in its short, rounded shape. The thickened part on its front border is apparently for articulation with the ascending process of the clavicle (Fig. 5, C). The foramen is the supraglenoid. The bone agrees closely with that figured by Case

[1] *Carnegie Publication, No. 146, (1911)* pp. 107 ff., A, B.

[2] *Bulletin American Geological Society*, XXI, Plate II, Fig. 1.

(*op. cit.*, p. 113), referred provisionally to *Zatrachys*. The coracoid has not been certainly recognized. The bone figured (Fig. 5, E, F) is probably correctly identified; possibly it is the ischium. There are no other evidences of pelvic bones, except of the ilia, of which more than fifty are in the Chicago collections. I have figured the relations of the quadrate in a specimen in which the different elements had been separated (Fig. 3). The sutural roughening for the pterygoid is very conspicuous. The separated quadrate is not very rare in collections.

Not a trace of any dermal ossicles has been detected in any of the abundant material; the skin unquestionably was bare. Certain skin ossifications or calcifications, however, have been detected in a few specimens, first mentioned by Cope and later by Case. They consist of very thin sheets, like leaves of thin paper, probably of calcified cartilage, overlying each other, a dozen or more, in places. They probably sheathed the under side of the abdomen.[1]

The bones figured were all found dissociated, and probably belong to different species, though there is not much difference in size. A number of species of *Trimerorhachis* have been described, though it is a futile and almost hopeless task to identify them. I assume that the skull and pectoral girdle belong to *T. insignis*, because they agree, so far as I can determine, with the species so named. I cannot forbear entering a protest here against the heedless naming of species of fossil reptiles, and especially of the Permian vertebrates, based upon fragmentary material or, much worse, upon difference in size. Such names seldom advance science. Nor does anyone care much, at the present time, about species; they are, for the most part, a nuisance. Specific determinations will become of use only when precise differences

[1] Rather singularly dermal ossicles have very rarely been observed in the air-breathing vertebrates of the American Permian—so far as I am aware only in *Eryops*, though ventral ribs or scales are a rather common characteristic of the reptiles. Very recently I have observed in *Pantylus*, the strange reptile of which only the skull has been known hitherto, a continuous covering extending probably over the whole body, though possibly only on the under side, composed of a mosaic of small, smooth, bony scutes two or three millimeters in diameter. The vertebrae and ribs show as great peculiarities as does the skull.

are required for geological correlations, or for minor problems in evolution, and their naming should, so far as possible, be deferred until much more material is available for comparison. As I have said elsewhere, the genus is practically our unit for most of the older vertebrates. In very few of the Permian vertebrates do we yet know what specific differences really are; we have few measuring sticks yet to measure them by; and it is only the morphological characters of the genus and higher divisions that concern us much in paleontology. Perhaps this protest is a sort of belated

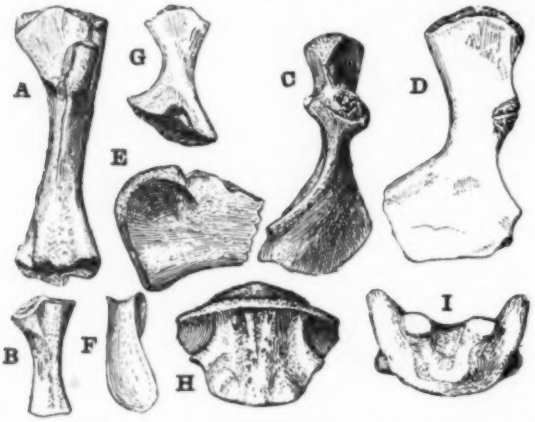

FIG. 6.—*Trimerorhachis*. *A*, left femur, from behind; *B*, tibia; *C*, humerus, radial side; *D*, another humerus, dorsal side; *E*, coracoid (?); *F*, the same, end view; *G*, right ilium, outer side; *H*, anterior intercentrum, from below; *I*, the same, from behind. All figures three-fourths natural size.

repentance on the part of one who has himself contributed hundreds of specific names to zoölogical and paleontological literature, but the many hours he has spent in the endeavor to identify organisms from vague and imperfect descriptions at least give him the right to urge temperance in the making of more or less worthless types! About twenty-five specific names were given to the mosasaurs of Kansas. The most diligent search of abundant material has resulted in the recognition of scarcely a half-dozen. The same fate probably awaits the great majority of the specific names which have been given to the Permian vertebrates.

There are various species among the material known as *Trimerorhachis;* of that there can be no question; as also of *Eryops;* but when one species is based upon an isolated scapula, for instance, another on the comparative size or minor distinctions of a skull, and a third upon a vertebra, one is tempted to ask: What is the use?

It need not be said that the differences of occipital condyle, pectoral girdle, vertebrae, and limbs in *Trimerorhachis* are of more than family importance. Doubtless some day, when we know the forms better, the genus or genera will be separated into a group of higher rank.

THE GEOLOGY OF LIMESTONE MOUNTAIN AND SHERMAN HILL IN HOUGHTON COUNTY, MICHIGAN[1]

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Limestone Mountain and Sherman Hill consist of three small residual masses of dolomite in southeastern Houghton County, Michigan. The first is partly divided and is locally known as Big and Little Limestone. These paleozoic outliers have been the subject of some previous study, but the visits of the geologists have been brief and the work incomplete. During the summer of 1913 the authors spent six weeks in the region in an attempt to determine the exact age and structure of the beds. The result of this work will be published in full by the Michigan Geological Survey, but the results obtained contain so much of interest that a brief preliminary report seems desirable.

Limestone Mountain lies half a mile east of the little station of Hazel on the Mass City branch of the Mineral Range Railroad and directly north of the track. Sherman Hill lies one and a half miles northeast of Limestone Mountain.

The fossils collected were determined by the junior author and finally submitted to Dr. E. O. Ulrich of the United States Geological Survey for revision and for the determination of the exact horizons. For this and for many helpful suggestions we desire at this point to express our thanks to Dr. Ulrich.

As finally determined, the stratigraphy of the beds is as follows:

Mid-Devonian.—All that is known of this horizon is a single mass of chert protruding from the talus on the southeastern slope of Big Limestone. It yielded four fossils:

Chonetes coronatus var.
Productella cf. *navicella* and *spinulicosta*
Spirifer aff. *pennatus*
Cystodictya cf. *hamiltonensis*

[1] Published by permission of the director of the Michigan Geological Survey.

These fossils are few in number but so characteristic that there can be no doubt of the presence of mid-Devonian rocks in or near Limestone Mountain.

Niagaran (*Lockport*).—A bed of very siliceous material was found on the south slope of Big Limestone. It could not be traced for any very great distance nor could any satisfactory determination of its position be made. No trace of a similar layer was found in any other outcrop. The fossils collected are:

Streptelasma spongaxis
Zaphrentis stokesi
Duncanella(?) sp.
Clorinda cf. *ventricosa*
Pentamerus sp.
Chonchidium decussatum(?)
Dalmanella cf. *elegantula*
Leperditia aff. *cylindrica*
Loxonema sp.

Middle to Upper Richmond.—Three fossils were found with the Niagaran material which show the presence of this horizon, but the bed could not be distinguished stratigraphically from the Niagaran.

Favosites asper
Columnaria alveolata
Plectorthis whitfieldi

Upper part of the Lower Richmond (*Arnheim*).—Near the southeastern corner of Big Limestone a thin layer of dolomite was found in the bottom of a deep gully. The layer was almost perpendicular, but as it was in the zone of broken talus we cannot be sure that it was in place.

Crinoid columnals
Coeloclema oweni
Mitoclema minutum
Mesotrypa patella
Bythopora striata
Rhynchotrema perlamellosa
Rhynchotrema capax
Conularia formosa
Primitia cincinnatiensis
Tetradella persulcata var.

Ceratopsis robusta
Calymene, a new species allied to *C. fayettensis* and *C. mamillatus.*
Conodont

Lower Richmond.—A bed about ten feet thick occurs at the top of Little Limestone and on the southeastern slope of Big Limestone which contains fossils of this age. The matrix is siliceous and the fossils are, as a rule, silicified.

Streptelasma rusticum(?)
Halysites gracilis
Iocrinus aff. *I. crassus*
Orbiculoidea (*?Schizotreta*), n. sp.
Rafinesquina, n. sp.
Leptaena unicostata, two new varieties
Plectambonites sp.
Plectorthis whitfieldi
Plectorthis kankakensis
Dalmanella aff. *rogata*
Dinorthis subquadrata
Hebertella, n. sp. aff. *H. insculpta*, *H. fausta*
Platystrophia sp.
Rhynchotrema capax

Galena (*Stewartville or Upper Galena*).—Sixty feet of heavy-bedded, cream-colored dolomite beneath the Lower Richmond on Little Limestone and at the top of Sherman Hill. The fossils occur near the top of the bed.

Cyrtolites cf, *retrorsus*
Liospira cf. *angustata*
Hormotoma(?) major
Lophospira minnesotensis
Maclurea crassa
Maclurina manitobensis
Maclurina cuneata
Trochonema umbilicatum
Fusispira subbrevis
Spiroceras sp.
Salpingostoma cf. *expansa Hall* and *buelli Whitfield*

Decorah (*Upper Blue*).—Below the last-described layer there is an old quarry on the eastern face of Little Limestone in a thin-bedded dolomite. The top layers are gray, the lower layers cream-colored with blotches of dark-red iron stain. Identical fossils

occur in both layers. A layer similar to the lower one, occurring on Sherman Hill, also carries Decorah fossils but shades up into the heavy dolomite without the intervening thin-bedded layer. The fossils found in the quarry are:

Crinoid columnals
Ceramophylla frondosa
Trematopora(?) primigenia
Halloporina crenulata
Arthrostylus sp.
Arthroclema sp.
Rhinidictya mutabilis
Rhinidictya fidelis(?)
Arthropora simplex
Escharopora subrecta
Escharopora confluens
Orthis tricenaria
Streptelasma profundum
Strophomena incurvata
Strophomena septata
Dalmanella rogata(?)
Hormotoma salteri canadensis
Aparchites sp.

Upper Black River (*Upper Bluff*).—At the extreme southwestern part of Big Limestone and eight feet above the sandstone there occurs a heavy-bedded, cream-colored, fossiliferous layer of dolomite. The beds above and below are completely barren, so far as we could determine.

Ctenodonta nasuta
Ctenodonta gibberula
Endodesma(?), n. sp.
Cyrtodonta billingsi
Cyrtodonta cf. *billingsi*, n. sp.
Cyrtodonta cf. *huronensis* and *subcarinata*
Cyrtodonta cf. *tenella*
Cyrtodonta, n. sp.
Vanuxemia aff. *niota Hall* and *subrotunda Ulrich*
Vanuxemia sp.

Potsdam (*Jacobsville*).—This is the lowest horizon in all the outliers and the only stratum which was observed at all three localities. It is a dull-brown, coarse, poorly cemented sandstone with

occasional streaks of a very fine conglomerate or a very coarse sandstone. On Big Limestone and Little Limestone the pebbles of the conglomerate are of quartz and about the size of a pea; near Sherman Hill the pebbles are larger and there is much chert and greenstone. No fossils were found in this layer. It has been referred by Lane to the Jacobsville Sandstone, probably of Potsdam age.

The hills are broken in a very intricate manner by minor faults of comparatively recent age. They are, in many cases at least, due to under cutting of the dolomite and to slumping. There are some major faults, notably the one between Big and Little Limestone, which involve the sandstone below. Unfortunately the data available do not serve to determine the age of the great Keweenawan fault; the most that we can say is that there was serious disturbance of the region at least as late as after mid-Devonian time.

The most important point brought out by this study is the demonstration that the paleozoic seas of the times mentioned above extended well into, if not over, the Northern Peninsula of Michigan, and our paleogeographic maps must be so far altered as to include that region within the areas of deposition. Dr. Ulrich has called attention to the similarity which exists between the Pentameroid forms of Big Limestone and those of the Far West indicating a broad extension of the Niagaran sea in that direction.

In conclusion the senior author desires to state that most of the field work and the determination of the fossils was done by the junior author and that to him in a large measure is due the credit for the recognition of the extension of the paleozoic sea over the Northern Peninsula of Michigan.

SUMMARIES OF PRE-CAMBRIAN LITERATURE OF NORTH AMERICA FOR 1909, 1910, 1911, AND PART OF 1912

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III. LAKE SUPERIOR REGION AND ISOLATED PRE-CAMBRIAN AREAS OF THE MISSISSIPPI VALLEY

Adams[1] states that the formations of the Cuyuna iron-bearing district of the north-central part of Minnesota consists of a series of complexly folded Upper Huronian slates and other clastics interstratified with lenses of iron formation, and intruded by basic Keweenawan rocks; the whole trunkated and almost completely covered by patches of Cretaceous conglomerate and a thick mantle of glacial drift, presenting a surface of gentle relief.

The iron formation occurs as a series of parallel and overlapping lenses or belts, generally associated with magnetic attraction on the limbs of trunkated anticlines, trending northeast-southwest. It presents all gradations between original cherty iron carbonates, and its secondary phases, ferruginous cherts, hard, soft, low-grade hematite ores, and amphibole magnetite rocks.

Adams follows Van Hise and Leith in his belief that the ores occur in places which have been favorable to the circulation of surface solutions, such as in inclined basins formed by pitching folds superimposed on the major anticlines or by the intersection of dikes with the walls adjacent to the iron formation lenses. Since the ores in such localities grade into ferruginous cherts, and cherty iron carbonates where the circulation of solutions was less favorable, he concludes that the ores have resulted from the oxidation of the cherty iron carbonates to ferruginous cherts and from the latter by the leaching of the silica. The amphibole magnetite rocks probably have developed from the anamorphism of cherty iron carbonates.

[1] Francis S. Adams, "The Iron Formation of the Cuyuna Range," *Econ. Geol.*, V, No. 8 (1910), 729–40; *ibid.*, VI, No. 1 (1911), 60–70; *ibid.*, VI, No. 2 (1911), 156–80.

Allen[1] reports that the stratigraphic succession in the Iron River district of Michigan from the Brule river northward consists of fine-grained, ellipsoidal basalts, and green schists probably Keewatin; Lower Huronian cherty and slaty dolomite, quartzite, and slates; Upper Huronian slates and graywackes, containing iron formation lenses in at least four horizons, and associated with basic igneous rocks, mainly extrusive. Unconformities between the major units are inferred but not known, owing to the drift-covered condition of the contacts.

The rocks are complexly folded, but the details of the structure are obscure. The major axis of folding is northwest-southeast in the eastern part of the district, east and west in the central portion, and southwest to northeast, farther west.

The Upper Huronian is divisible into three main belts or stratigraphic horizons running parallel to the major structure, that near the Brule River on the south being the lowest. The southern belt consists dominantly of slates and iron formation lenses, the productive portion of the district. The next overlying belt is ill defined, consisting dominantly of extrusive greenstones. The uppermost belt, lying farthest north, consists of slates, graywackes, basic extrusives, and iron formations.

The iron formations comprise slaty and cherty iron carbonates, ferruginous cherts and slates, magnetic, chloritic, sideritic slates, altered greenalite, and secondary soft, hydrated hematite ores. The ore bodies occur mainly as irregular sheetlike masses parallel to the bedding or as pockets related to structural basins. They are bounded by phases of lean iron formation, extrusive basic rocks, or carbonaceous shale, or any combination of these.

Buckley[2] confirms Haworth's conclusions that the pre-Cambrian rocks of Missouri consist of contemporaneous granites and rhyolites intruded by diabase dikes. About 200 feet of slate and conglomerate are exposed on Pilot Knob. The igneous rocks are correlated by Buckley with the Laurentian and the sediments with the Huronian, but the reasons for this correlation are not evident.

[1] R. C. Allen, "The Iron River Iron-bearing District of Michigan," *Mich. Geol. and Biol. Surv.*, 1910, 144 pp., 17 pls., 18 figs.

[2] E. R. Buckley, "Geology of the Disseminated Lead Deposits of St. François and Washington Counties, Missouri," *Missouri Bur. Geol. and Mines*, IX (1908), Pt. 1, 259 pp., 39 pls., 10 figs.

Crane[1] describes the pre-Cambrian iron ores of Iron Mountain, Missouri, as veins of specular hematite containing apatite and tremolite, which occur in porphyry; and detrital ores derived from the vein ores. The ores of Shepherd Mountain near by are also vein ores, but their principal constituent is non-titaniferous magnetite, with pyrite and a little clay. The Pilot Knob ores are soft blue, banded hematites, locally with ripple marks, and rest conformably on a nearly smooth floor of porphyry, and grade laterally into a porphyry breccia. The formation is separated into two parts by a claylike bed. The ore above the claylike bed is more distinctly stratified and grades upward into a hundred feet of breccia.

Crane concludes that these ores represent replaced tuffs, from the fact that they grade into breccias both along the strike and the dip. It has been found extremely difficult to explain the origin of the Pilot Knob ores under any hypothesis offered thus far. This is due in large part to the fact that only a small remnant of the ores, and the rocks associated with them have been left by erosion. The principal objection to the replacement hypothesis is found in the interstratification of non-iron-bearing materials with the ores. Under the replacement hypothesis it would be necessary to assume that the replacement of certain layers was accomplished, while others remained unaltered.

Crane does not correlate the pre-Cambrian rocks of Missouri with certain Lake Superior pre-Cambrian rocks, as some of his predecessors have done.

Grout[2] infers from analyses of Keweenawan diabase in different stages of alteration that the fresh rocks contain more copper than the altered, the copper being in the form of a basic silicate in the fresh rock, and that the more basic diabases originally contain more copper than the more acid types.

Grout[3] finds that chemical and mineralogical analyses of the Keweenawan lavas of the Kettle River region of Minnesota indicate

[1] G. W. Crane, "Iron Ores," *Missouri Bur. Geol. and Mines*, Vol. X, (1912) pp. 36–39, 107–44.

[2] Frank F. Grout, "Keweenawan Copper Deposits," V, No. 5 (1910), 471–76.

[3] F. F. Grout, "Contribution to the Petrography of the Keweenawan. *Jour. Geol.*, XVIII, No. 7 (1910), 633–57.

a close magmatic relationship between them and ascribes the differences to differentiation.

Analyses of fresh lavas containing 0.01 to 0.03 per cent of copper are cited by him as proof that the Keweenawan ores were derived from the lavas. This conclusion is open to the objection that a similar content of copper has been found in many rocks where no ores were developed.

Lane[1] finds that the waters from the deep levels of Michigan iron mines are high in sulphates and chlorides which are associated with calcium rather than sodium. The carbonate radical is low and decreases with depth. Their silica content is like that of ordinary cold surface waters, and they contain almost no iron.

A. C. Lane and A. E. Seaman[2] divide the pre-Ordovician of Michigan into Keewatin, Huronian, and Cambrian or Primordial. The Keewatin corresponds to the Archaean; the Huronian to the Algonkian; and the Cambrian or Primordial to the Keweenawan and Potsdam of Van Hise and Leith. Lane believes that the Potsdam and Keweenawan should not be placed in different geologic periods because of their stratigraphic and structural similarity and continuity, and because no unconformity can be found between them.

Lane[3] recognizes the following groups of Upper Michigan Keweenawan rocks from the base upward: (1) Bohemian Range group: consisting mainly of basic lavas but with intrusive and and effusive felsites and coarse labradorite porphorites; also intrusive diabase dikes and gabbro aplites, with a total thickness of about 9,500 feet; (2) the central mine group: mainly lavas of an augitic ophite type with infrequent sediments; this includes the Allouez conglomerate, the Calumet and Hecla conglomerate, and the Kearsarge lode; the total thickness is placed at from 3,823 to 25,000 feet; (3) the Ashbed group: consisting of basic lavas of the

[1] A. C. Lane, "Michigan Iron Mines and Their Mine Waters," *Jour. Can. Min. Inst.*, XII (1909), 114–29.

[2] Notes on the Geological Section of Michigan," part of *Annual Report* for 1908, Michigan Geological Survey, 1909, 120 pp.

[3] A. C. Lane, "The Keweenawan Series of Michigan," *Mich. Geol. and Biol. Surv.*, 1909, 2 vols., 932 pp.

Ashbed type with scoriaceous sediments and a little conglomerate. The thickness may be between 1,456 and 2,400 feet; (4) the Eagle River group: a group of basic lava flows with frequent beds of sediments; its thickness is between 1,417 and 2,300 feet; (5) the Great Copper Harbor conglomerate: a coarse, heavy conglomerate from 1,800 to 2,200 feet thick; (6) the Lake Shore traps: a series of thin flows having a total thickness of about 800 feet; (7) the Outer Copper Harbor conglomerate: from 1,000 to 5,000 feet in thickness; (8) the Nonesuch shales: black, fine-grained, micaceous sands and grits, about 500 feet in thickness; (9) the Freda sandstones: red, impure sands, shales, and conglomerates; 4,000 or more feet in thickness.

The Keweenaw rocks dip at a high angle toward the north under Lake Superior and in general strike parallel to the axis of the Keweenawan Peninsula. They have also been disordered by numerous faults. The great Keweenaw fault, a longitudinal fault dipping toward Lake Superior and cutting across the bedding, is regarded by Lane as a thrust fault due either to the contraction of the earth's crust or to uplift produced by the injection of a large sill. Movement along this fault began before Cambrian time and has taken place since the deposition of the Niagara limestone. There are also other faults both parallel to the bedding and longitudinal faults which cut across the bedding. There are numerous vertical or nearly vertical transverse faults which have produced an offset of the beds to the right in going toward the northeast.

The Keweenaw rocks of northern Michigan as well as those of other parts of the Lake Superior region show strong evidence of consanguinity. Thus in all of these rocks potassa appears to be subordinate to soda except in extremely siliceous varieties, and in general the potass is very low. Free quartz is not abundant. There is never an excess of alumina which would result in the development of corundum nor are there any ultra-alkaline or ultra-basic rocks. The content of iron is decidedly high. According to Iddings' classification, the commonest type would be auverngnose. No rocks are known which contain less of both silica and alkalies.

Lane finds that the composition of these rocks is on the sodic side of a line which he regards as a hypothetical eutectic between

alkalies and silica. In harmony with this, he finds very few cases of porphyritic texture and very little difference in the time of crystallization of the various constituents. In general, labradorite has come out first and augite last in the dikes and flows, while in the deep-seated intrusives, the order is reversed. He also regards the development of olivine rather than enstatite or hypersthene as in harmony with the position of the analyses with respect to his hypothetical eutectic.

The igneous rocks are all crystalline. If any glass has existed in these rocks it has long since become devitrified. The following varieties of texture are described by Lane: (1) ophitic, in which the augite crystals occur as a cement, enclosing idiomorphic feldspars; this texture characterizes the central portion of the basic effusives; (2) doleritic texture, in which the feldspar is much coarser than the augite; (3) glomeroporphyritic or navitic, in which the feldspars present a great range of size and tend to aggregate in bunches; (4) porphyritic hiatal, characterized by coarse feldspar phenocrysts imbedded in a ground mass in which the feldspars are very small; (5) amygdaloidal texture in which blow holes have resulted from the escape of gases; (6) microlitic, a texture which develops around amygdules; it is characterized by fine slender prisms of feldspars; (7) vitrophyric, consisting of a glasslike ground mass in which a few crystals are imbedded; it is always found within a few millimeters from the margin; (8) the graphic texture, consisting of intergrowths of quartz and feldspar; it is very common in the interstices of the Bessemer gabbro and is also very abundant in felsite conglomerate pebbles; (9) spherulitic texture, found only in salic rocks; it is characterized by small spherules of rock; (10) mozaic texture, consisting of equigranular quartz and feldspar.

The factors which determine the grain of igneous rocks are stated by Lane to be the chemical composition, temperature, and pressure of the magma. He presents a mathematical discussion of the relation between grain and cooling.

The mean annual temperature of the air on Keweenaw Point is between 38° and 42° Fahrenheit. The temperature of the upper mine levels at a depth of from 100 to 236 feet varied from 43° to 50°, and the average was nearly 43°. The rate of increase of

temperature with depth is found to be very small, about 1° in 103 feet. Lane suggests that this low temperature gradient may be due to chemical reactions which absorb heat, such as the deposition of copper; the diffusivity of the strata, permitting the early and free escape of heat; downward absorption of water carrying with them cooler temperatures of the surface; recent deposition of surface drift, and the relative exhaustion of the internal supply of heat by the Keweenaw and earlier eruptions.

The mine waters of the region are of three types: (1) normal surface carbonate waters, in which calcium and magnesium are in excess of sodium; (2) waters of intermediate levels, 1,000–2,000 feet, high in sodium and chlorine, in which lime and magnesium are subordinate; (3) waters of deep levels in which lime chloride dominates, and in which magnesium is absent or nearly absent and sodium subordinate. Waters of type (2) are associated with the richest part of the lodes and with the occurrence of silver. The deep waters are regarded by Lane as connate waters, but not necessarily derived from the ocean of that time.

Lane regards the lavas and sediments as the original source of the copper. All the lavas and sediments contain at least 0.02 per cent or more of primary copper. The lavas and sediments he believes were deposited rapidly one upon the other, the lavas retaining their heat for a long period of time. Water and gases containing chlorine were given off by these lavas and these caused a hydration of the silicates of the rock, developing chlorite and epidote and some native copper. This first alteration, however, he believes was insufficient to account for the development of all the copper, since the occurrence of the copper in the porous parts of the formation indicates that circulation of water must have taken place. The circulation which Lane believes developed the ores was set up largely through the cooling of the rocks. As the rocks cooled they contracted and afforded openings for water which was sucked in from the surface. A large part of this water entered into chemical combinations with the rocks and thus a very strong and long-continued downward circulation must have been set up, since the greater portion of the rocks have been hydrated to chlorite. This reaction also involved solution of sodium silicate, copper, and lime

in the form of chloride. The precipitation of the copper Lane believes took place according to the experimental results of Fernekes, the copper being taken out of solution by means of ferrous chloride in the presence of alkalies, principally in the form of calcite and prehnite and datolite, since the copper shows most intimate associations with these minerals.

Paige[1] states that the pre-Cambrian rocks of the Llano-Burnett region consist of a sedimentary series of gneisses and schists and banded iron formation lenses composed of alternating layers of magnetite, quartz, and silicates, the whole intruded by a large development of granites and minor basic igneous rocks.

Richardson[2] states that the lowest pre-Cambrian rocks of the El Paso district are white and red quartzites, fine, round grained, intruded by diabase dikes. About 1,800 feet are exposed in the Franklin Mountains. The dip of the beds is 20°–45° west. They are separated by a slight unconformity from 1,500 feet of massive red rhyolite porphyry overlying them. The rhyolite is separated by a marked unconformity from the Cambrian beds above it.

Sharwood[3] publishes a large number of analyses of the rocks, minerals, ores, and waters of the Homestake mine, as a supplement to *Professional Paper No. 20* of the U.S. Geological Survey.

Steidtmann[4] finds that a minority of the joints of the Baraboo quartzite are clearly related to the local folding; namely, joints parallel to the bedding, and strike joints which dissect the bedding. The abundance of the joints is related to the intensity of the folding. The majority of the joints are vertical, gaping, continuous cracks, which are not related to the local folding, but probably belong to larger units of structure.

Todd[5] states that the pre-Cambrian rocks have been penetrated by borings in the Aberdeen-Redfield quadrangles of South Dakota.

[1] Sidney Paige, "The Mineral Resources of the Llano-Burnett Region, Texas," *Bull. 450, U.S. Geological Survey*, 1911, pp. 103, maps and illustrations.

[2] G. B. Richardson, "The El Paso Quadrangle," *U.S. Geological Survey, Folio 166*, 1909, 11 pp., 2 pls., maps, etc.

[3] W. J. Sharwood, "Analyses of Some Rocks and Minerals from the Homestake Mine, Lead, South Dakota," *Econ. Geol.*, VI, No. 8, pp. 729–89.

[4] "The Secondary Structures of the Baraboo Quartzite," *Jour Geol.*, XVIII, No. 3 (1910), 259–70.

[5] J. E. Todd, "The Aberdeen Redfield Folio," *U.S. Geological Survey, Folio 165*, 1909, 13 pp.

They include a quartzite, believed by Todd to be the Sioux quartzite, granite, and mica schist.

F. T. Thwaites[1] concludes that the sandstones of the Wisconsin coast of Lake Superior form a single conformable series, which may be separated into two groups, which grade into each other, viz., a lower group, consisting of steeply tilted red feldspathic sandstones and fragments of igneous rocks, shales, and conglomerates; and an upper group, composed of slightly disturbed red and white quartz sandstones. The contact of the upper group with the Middle Keweenawan traps is marked by a thrust fault. A small amount of conglomerate in the sandstones along this contact may indicate a local unconformity. Since the faulting, folding, and erosion of the traps and the deposition of the sands went on simultaneously, there is no reason for believing that this conglomerate represents a great time interval, if indeed any. Irving placed the upper group in the Cambrian since he regarded the sandstone faulted against the Middle Keweenawan traps at St. Croix Falls and the same in age as the sandstone at the falls of the Amnicon River. Thwaites shows that the former is Upper Cambrian, but that the latter is older.

The conditions of deposition of the sandstones appear to have been dominantly subaerial as indicated by current marks, mud cracks, rain prints, irregular and curved bedding, depressions in shale beds filled with sands, red color, and feldspathic content.

The relations of these sandstones to the known Cambrian of Wisconsin is still doubtful. Thwaites points out certain differences between them. The Cambrian is marine as shown by fossils, and its sands generally consist of rounded, yellow quartz grains often enlarged so as to show crystal faces, and cemented dominantly with calcite. The sandstones of the Lake Superior coast lack fossils and were largely deposited under subaerial conditions. Their feldspathic content, angular grain, irregular quartz enlargements, red color, irregular and curved bedding, and lack of calcite cement contrasts strikingly with the characteristics of the known Cambrian.

Van Hise and Leith's[2] "The Geology of the Lake Superior Region" is a summary of the geology of the Lake Superior region.

[1] F. T. Thwaites, "Sandstones of the Wisconsin Coast of Lake Superior," *Wis. Geol. and Nat. Hist. Surv. Bull. 25*, 1912, pp. 109.

[2] "The Geology of the Lake Superior Region," *U.S. Geological Survey, Monograph 52*, 1911, 641 pp., 49 pls., 76 figs.

Their conclusions on the origin of the sedimentary iron formations from which the ores were derived by secondary concentration will be considered here. The unaltered iron formations consist essentially of alternating bands of chert, iron carbonate, oölitic greenalite, and iron oxides, varying in thickness from a few feet to more than a thousand feet. It is inferred that they are chemical sediments from their composition, lack of fragmental texture, and bedding. They show a great variety of lithologic associations, subaqueous ellipsoidal greenstones, tuffs, acid extrusives, and normal sediments, viz., quartzites, limestones, and slates.

From the fact that the iron content of the thick formations and the sediments associated with them is greater than the iron content of the rocks which antedate them, and since normal weathering tends to fix iron in place rather than to cause its transportation and deposition elsewhere on a large scale, it is concluded that the iron in these thick iron formations is not the result of a normal cycle of erosion, but was contributed from some unusual source. Further evidence for this conclusion consists in the fact that their thickness, composition, and structural characteristics do not resemble either the bog or the glauconite deposits of the present time. Furthermore, their calcium-magnesium ratio is the reverse of that prevailing in normal sediments. On the other hand, the small bodies of iron formation, particularly those interbedded with slates, are similar in their composition, thickness, and association to deposits formed by the solution, transportation, and deposition of iron by processes of normal weathering. The unusual source of iron as well as of the silica of the thick deposits Van Hise and Leith believe may have been from the submarine extrusions of basic lavas, with which the iron formations are more or less associated in time and in place. They postulate that the lavas may have contributed the iron solutions directly, or that iron solutions may have been formed from the interaction of the hot lava and sea water, and that the lavas may have furnished iron solutions by weathering.

They show that salt water acting on hot basalt forms sodium silicate, and that sodium silicate in the presence of iron salts will form oölitic iron silicate and silica which are thrown down in alternating bands, and that when carbonic acid gas is present, iron carbonate

may form instead of the silicate, while in the presence of abundant oxygen, the development of alternating bands of ferric oxide and silica may take place. Thus by simple laboratory reactions, the composition, textures, and structures of the Lake Superior iron formations are duplicated.

The monograph cites a number of cases of the intimate association of sedimentary iron formations of various ages with eruptive rocks in places outside of the Lake Superior region, but fails to name one of the most striking cases which presents a close parallel to that of the Lake Superior region, namely, the oölitic, banded, marine Devonian hematites of the Harz Mountains, which are intimately associated with subaqueous basalt extrusions, diabase, tuffs, and limestones.

Wright[1] discusses the relations of the ophites, oligoclase gabbro and aplite of Mount Bohemia at Lac La Belle on Keweenaw Point.

The oligoclase gabbro is intrusive into the ophite flows, but the aplite inclosed by the gabbro is regarded as a differentiate from the gabbro. The process of differentiation is supposed to have been accomplished by fractional crystallization, convection currents, and general upward movement of the lava. The intrusives contain veins of sulphides and arsenides of copper which are regarded as genetically related to the native copper deposits in higher horizons of the ophites. The contact metamorphism of the ophites by the gabbro is slight. Diopside has changed to uralitic hornblende, and there is a slight increase in silica and oxidation of iron at the contact.

[1] F. E. Wright, "The Intrusive Rocks of Mount Bohemia," part of *Ann. Rept.* for 1909, Michigan Geological Survey, 32 pp.

[*To be continued*]

DISCOVERY OF THE NORMANSKILL GRAPTOLITE FAUNA IN THE ATHENS SHALE OF SOUTH-WESTERN VIRGINIA

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During the last year, as opportunity was afforded, the writer has had under investigation a Cambro-Ordovician section in southwestern Virginia, not only as a contribution to our knowledge of the geology of this section of Virginia, but more especially for the purpose of correlation, if possible, with the standard section north. In connection with this work the discovery was made that the Athens shale abounds in graptolites. The determination of some thirty or more species and varieties shows that the majority, if not all, are the same as those which characterize the Normanskill shale of New York.

As the paper on the entire Cambro-Ordovician section will not appear for some months, this occurrence is thought of sufficient moment to warrant the publication of this note in advance.

A number of papers have appeared in recent years discussing the Normanskill graptolite fauna and the correlation of the shales containing it. The literature on the subject shows that the formation has, from time to time, been referred to every possible position from the Hudson River formation to the Chazy. In 1901, however, Dr. Ruedemann showed[1] that the slate which contains this fauna in the Hudson River region underlies the Utica slate, and correlated it with the lower or middle Trenton. This correlation, based almost entirely on paleontologic evidence, is in general accordance with the views held by R. R. Gurley, H. M. Ami, and Charles Lapworth. Later, in 1903, Weller found the fauna in New Jersey, and, from his study of the beds containing it, concluded that they are about equivalent to the middle portion of the

[1] *Bull. 42, N.Y. State Mus.*

typical Trenton limestone of New York, or even to a position below the middle.

Dr. Emmons long ago expressed the belief that the formation extended through to Virginia, but very little is reported of it from the south. Professor E. A. Smith, state geologist of Alabama, reports a small fauna of about eight species occurring in calcareous shale associated with Trenton limestone, which he believes to be upper Trenton. This find, however, could demonstrate nothing more than the general fact of the Trenton age of the Normanskill fauna. Stratigraphic proof of the age of the formation has not been found in New York for the reasons stated by Ruedemann, that the whole mass of rocks, which contains Trenton, Utica, and Lorraine beds in similar lithologic development, is in New York as well as in Canada cut off from the neighboring terranes by extensive faults, thus apparently frustrating all attempts at a stratigraphic solution of the problem. As the primary object of this preliminary note, in addition to calling attention to the many species of graptolites occurring here, is definitely to locate on stratigraphic grounds the exact position of the formation containing this fauna, a description of the relevant portion of the section is given.

The Cambro-Ordovician section under investigation is in Roanoke County, Virginia, about 11 miles north of Salem, and extends from the top of Catawba Mountain northward across Catawba Valley to the foot of North Mountain, a distance of about 6,000 feet. This section is characterized by the unusual occurrence of all the strata from top to bottom in regular chronologic order, there being no faults or folds to disturb the natural sequence. Furthermore, the strata are most favorably disposed for observation, dipping at an angle of 45° on Catawba Mountain, and gradually rising to 70° in the valley. The new state road just being graded down the side of the mountain and across the valley exposes every stratum in the section from the top of the Medina on the south face of Catawba Mountain to the base of the Cambrian at the foot of North Mountain.

At the latter point there is a fault bringing the Carboniferous in conjunction with the Cambrian, which terminates the section. The section therefore includes every stratum from the top of the

Medina to the base of the Cambrian, with each in practically normal development. The section embraces the following members:

Medina sandstone, gray sandstone, quartzitic	400–500 feet
Sevier shales, calcareous shales and sandstones, and bluish-gray impure limestone. All very fossiliferous	1,200 feet
Utica shale, fossiliferous blue to black shales, and limestones with shale partings	300 feet
Tellico sandstone, red and gray sandstones	400 feet
Trenton, dark gray-blue, and black limestones with shale partings	500 feet
Athens shale, black carbonaceous shales, carrying graptolites, trilobites lingulas	560 feet
Black River, coarse dark coralline limestone with bands of smoky marble in upper part	250 feet
Birdseye (Lowville), pure dove limestone, with Tetradium	50 feet
Chazy, cherty magnesian limestone, with Maclurea magna	500 feet
Beekmantown, pure and impure, cherty and magnesian limestone	1,700 feet

As the Ordovician is now known to extend as far south as Alabama, evidenced by the finding of Ordovician graptolites by Professor E. A. Smith, and as the writer has found Ordovician fossils in the black slates in eastern Virginia, and as the Ordovician is known to occur far to the north and west of this point, it is but fair to presume that the sediments represented in the rocks of this section were laid down far within the confines of that ancient sea and that the section is therefore in normal development. Furthermore, as will presently be shown, the fossils—graptolites and others—occurring here are the same as those found in equivalent strata in New York and Canada, and Dr. Ruedemann makes the statement that the essential identity of the Alabama fauna with the Normanskill graptolite fauna cannot be gainsaid. It therefore seems most probable that the sea was open and continuous from Alabama to Canada, and that sedimentation was virtually the same throughout. The section here should, therefore, be practically the same as in New York. A notable difference occurs in the Tellico sandstone, which, however, may be but an expansion of the Dolgeville shale, a name proposed by Cushing in 1909 for the shaly phase of the upper Trenton which he previously described as "Trenton Utica passage beds." It may therefore be stated with greater

confidence that the Catawba section is normal and in general accord with the section north.

The Utica consists of two parts. The upper is slaty or shaly and more or less calcareous, carrying several species of corals and brachiopods, while the lower part is slaty limestone and limestone beds with some shale partings. The thin beds, which vary in thickness from one to four inches, are largely made up of brachiopods. The Tellico beneath is composed of red and gray sandstone and shale, with a massive, hard, quartzitic, ferruginous sandstone 30 feet thick at its base. It carries in addition some kaolin and flakes of mica. This basal member rests immediately upon the Trenton. The formation is about 300 feet thick. The Trenton limestone is conformable with the Tellico above, the two dipping at an angle of 60° S. The contact between them is sharp and clear. The limestone ceases suddenly as the sandstone comes in. The upper part of the Trenton consists of rather massive, dark, blue-gray limestone with some thin shale partings. The lower part is made up of alternating layers of solid black homogeneous limestone and thin bands of slate, the limestone bands varying in thickness from two to four to six inches. Fossils have not been observed except near the contact with the Athens shale, where a number of small trilobites were found. These probably belong to the Athens shale as the same species have since been found in the lower part of it. The Trenton formation is 500 feet thick, and passes into the Athens shale without perceptible break. Fresh-rock contact, however, has not been observed. On the surface there is frequently a slight depression due to differential weathering marking the contact. The Athens formation is compact, black, carbonaceous shale, slightly calcareous. The lower part contains some layers which are massive, and which resemble the Trenton limestone; but on examination the lime content is found to be no greater than in the more shaly portion above. The massive character is found to be due to less pressure having been applied to this part of the formation. It contains innumerable forms of *Dicellograptus sextans* which are not at all crushed or flattened, while the graptolites in the upper part of the formation are more or less flattened. These forms look as if they could be taken out bodily and sections of them be made for

microscopic study. The fossils show a smooth, polished, black, chitinous surface. Near the middle of the formation along with the various species of graptolites there are many forms of *Triarthrus becki*, and *Leptobolus walcotti*.

In New York the formation—Normanskill—carrying the same fossils is described by Ruedemann as a deep bluish-black, thick-bedded argillite with conchoidal fracture, and iron-stained cleavage. This description applies equally well to the Athens shale of Virginia. In *Folio 16 U.S.G.S.* Keith says of the Athens shale in Tennessee: "It is everywhere composed of blue and black shales, which do not vary in appearance. The black shales are found at the bottom of the series and contain lingula and numerous graptolites. The blue shales gradually replace the black shales in passing up through the series, and when fresh consist of thin light blue, shaly limestones." It is evident that the blue shales above the black, which he says consist of thin, light-blue, shaly limestone, represent the Trenton in that section, and the black shales below with the included graptolites and lingulae represent the Athens. Keith, in that section, also represents the Athens shale as immediately underlying the Tellico sandstone. Immediately below the Athens shale he describes a limestone formation consisting of massive blue and gray limestones, shaly and argillaceous limestones, and marbles. These beds are all very fossiliferous, and fragments of corals, crinoids, brachiopods, and gastropods are so abundant as sometimes to make most of the bulk of the rock. The upper beds of the formation consist of more or less coarsely crystalline marble. This is exactly the position of the marble beds in the Black River formation, and anyone at all familiar with it will see at once from the above description that the Athens shale of Tennessee, as well as that in Virginia, rests upon the Black River.

The conglomerate R. Ruedemann described[1] as occurring in the Normanskill of New York, although looked for, was not observed. Neither does the Rysedorph conglomerate occur here, which Ruedemann describes as intercalated in undoubted Normanskill, and containing in pebbles as well as matrix, as its youngest fossils, those of lower Trenton aspect. There does occur here, however,

[1] *Bull. 42, N.Y.S.M.*

a conglomerate at the base of the Lowville (Birdseye), separating it from the Chazy, which is in many respects like the Rysedorph conglomerate, but not in fossil content. While not essential to the points involved in this note, yet, for the sake of clearness, a brief description of it will be given when that point is reached in describing the section.

The mass of the Athens shale (Normanskill) dips at an angle of 70° S., and is about 550 feet thick. It occupies the center of Catawba Valley, which structurally is anticlinal, and through which meanders Catawba Creek. The shales where exposed in bluffs weather into thinly cleaved plates or leaves of a dark peppery gray on which the graptolites are not readily observed. The completely weathered soil is ocherous yellow, due to the presence of iron in the original rock. The fossils are in places preserved in pyrite, and as a rule where the seams open upon weathering the surface is rusty. On such surfaces the black fossils stand out clearly. The formation maintains its general character throughout, and terminates abruptly against the underlying Black River limestone, and does not here rest upon lower Trenton limestone. In this respect its position differs from the Normanskill of New York, for Ruedemann states in his summary that these shales rest on lower Trenton limestones. Mather, however,[1] in describing the Black River, in which is included the Lowville, several times states that the Black River is underlaid by a brecciated limestone and overlaid by slates. It would appear, therefore, that in certain localities, at least in New York, the succession of strata for this part of the Ordovician is the same as in Virginia; for these Black River limestones and slates of which Mather writes occur at Mount Moreno, and Mount Moreno is one of the four typical localities where complete or nearly complete Normanskill faunas have been collected. The conclusion to be drawn from the above is that the Normanskill there rests on Black River limestone as in Virginia.

The question has also arisen whether the Normanskill is a distinct development of the Ordovician or only a clastic phase of the Trenton. For this locality at least, it would appear to represent a distinct epoch in the Ordovician; for the formation is at least

[1] *Nat. Hist. N.Y.*, Part IV, "Geology," pp. 405-6.

500 feet thick, which is as thick as the Trenton above, and maintains its individual character throughout, in respect to lithology as well as fossil content. While no decided break or hiatus has been observed between it and the Trenton, yet there is a marked change in sedimentation. The shale deposit ceases and limestone appears, and along with it an entire change of life. Between it and the formation below the change in sedimentation is still more marked, for the fine black sediment of the Athens shale rests immediately upon the thoroughly crystalline limestone and marble of the Black River. The feature that would most closely associate the Athens shale with the Trenton is the occurrence of *Triarthrus becki* in the shale, but while it has been reported from the Trenton of other localities, it has not been observed to occur in the Trenton at this point. The Trenton here is singularly devoid of fossils. Everything considered, conditions here point to the same conclusion for the Athens shale as those reached by Lapworth, Ami, and Ruedemann for the Normanskill of New York, viz., that it represents a distinct epoch of the Ordovician.

The species of graptolites and other forms from the Athens shale thus far determined are as follows:

Climacograptus bicornis Hall
Climacograptus modestus
Climacograptus parvus Hall
Climacograptus putillus Hall, mut. eximus
Climacograptus putillus Hall
Climacograptus scalaris
Climacograptus typicalis Hall, mut. spinifer
Climacograptus scharenbergi Lapworth
Corynoides gracilis Hop., mut. perungulatus
Cryptograptus tricornis Carruthers
Dicellograptus sextans Hall
Dicellograptus intortus Lapworth
Dicranograptus spinifer Lapworth
Dicranograptus nicholsoni Hopkins
Dicranograptus ramosus Hall
Didymograptus serratulus Hall
Didymograptus sagittacaulis Gurley
Didymograptus subtenuis Hall
Diplograptus amplexicaulis Hall
Diplograptus angustifolius Hall

Diplograptus foliaceus var. incisus
Diplograptus foliaceus Murchison, var. acutus Lapworth
Diplograptus foliaceus
Dictyonema ———
Glossograptus quadrimucronatus Hall, var. cornutus
Lasiograptus mucronatus Hall
Leptobolus walcotti
Nemagraptus exilis Lapworth
Nemagraptus exilis Lapworth, var. linearis
Nemagraptus gracilis Hall
Phycograptus laevis (Graptolithus laevis Hall)
Retiograptus eucharis Hall
Triarthrus becki

An interesting feature of a number of these species is their occurrence in original colonies, or synrhabdosomes. Several species show synrhabdosomes which have not heretofore been observed. All of the above listed forms occur in fresh material, are very distinct, and apparently not at all distorted, or flattened. The graptolites occur in all parts of the formation from top to bottom.

The Black River formation beneath the Athens shale is made up of dark to black coarsely crystalline limestone and marble, 250 feet thick. It contains several distinct bands of marble between the middle and the top. One occurs at the top. The marble is of a smoky-gray color, rather coarsely crystallized, and fossiliferous. The bed near the middle is about 6 feet thick, the other beds somewhat less. The mass as a whole, except the lower part, appears to be a coral reef on which flourished crinoids, bryozoa, brachiopods, gastropods, and, in the lower part, orthoceratites. The lower part of the formation is more or less siliceous and cherty, which on weathering produces knots over the surface. The Black River was laid down on an unevenly eroded surface of dove-colored limestone, the Lowville (Birdseye). The hiatus here shown is well marked. A sharp line can be drawn between the coarse, dark, impure limestone above and the pure fine-grained, dove-colored limestone beneath. The Lowville contains *Tetradium cellulosum* in abundance, and near the bottom large, coiled shells. The formation is about 50 feet thick and terminates in a very coarse, brecciated limestone conglomerate, which separates it from the Chazy below.

This appears to be a basal conglomerate. It is composed of fragments ranging in size from an eighth of an inch to pieces 6×15 inches. They consist of angular grains and pebbles of quartz, pieces of dark chert 4×6 inches, large blocks of magnesian limestone, and angular fragments of all sizes from the underlying cherty magnesian limestone of the Chazy and Beekmantown formations. The fossils, among them *Ophileta*, are imbedded in such a manner with the fragments as to indicate that they were fossils when inclosed. The conglomerate is from 6 to 8 feet thick. This evidently is the conglomerate referred to by Mather as occurring at Mount Moreno. It is in all probability the basal conglomerate described by Weller from New Jersey. The writer has noted its occurrence in Maryland and at several places here in southwestern Virginia. It has been observed here at two points, in the same stratigraphic position, 12 miles apart at right angles to the strike, showing that the sea was encroaching upon the land, beating down the ancient Chazy-Beekmantown limestone cliffs, and scattering the fragments along the shore from Canada to Tennessee[1] as the sea advanced.

Enough of the section has now been described to locate definitely the stratigraphic position of the shales carrying the Normanskill graptolite fauna. It is evident that the position assigned them here, below the Trenton and above the Black River, is correct for Virginia and Tennessee, and is in harmony with the statement of Mather for part of New York. It is also in general accord with the views entertained by Ami, Lapworth, and Gurley, who, on paleontologic evidence only, thought the fauna should be placed in lower Trenton if not below the Trenton.

Dr. Ruedemann[2] admits the essential identity of the Alabama fauna with the Normanskill, but says it is open to question whether this upper Trenton of Alabama is exactly equivalent to that of New York. In the light of the manifestly clear section in southwestern Virginia, it is difficult to see how these same shales could be upper Trenton in Alabama. Furthermore, the section as given

[1] Keith describes a similar conglomerate "of unknown age" from that state, which, from his description (*U.S. Folio 16*), is in all probability the same.

[2] *Mem. II, N.Y.S.M.*, p. 12.

by Professor Smith reads as if the strata were very much faulted, folded, or otherwise disturbed. The graptolite beds are seen to be alternating with beds of chert and sandstone, and they are stated to occur at the top of the series, not far below chert beds with sub-Carboniferous fossils. The latter indicates either profound thrust faulting or an interval of non-deposition.

While the evidence gathered by those who, in the North, have been wrestling with the problem of the age and stratigraphic position of the Normanskill graptolite fauna points to nothing more definite than probably lower Trenton, and no further extension south than the present site of New Jersey in the Appalachian geosyncline, it is believed that the facts here presented definitely fix both age and position, and at the same time show a southern extension as far as Tennessee.

SUMMARY

The great number of graptolites occurring in the Athens shale of Virginia, and the fact that nearly all of those thus far identified are Normanskill forms, leaves no doubt as to the identity of this fauna with that of the Normanskill. The Athens shale carrying this fauna is to be correlated with the Normanskill shale of New York.

The stratigraphic position of the Athens shale in southwestern Virginia is clearly below the Trenton and above the Black River, and it seems probable that when discovered at points intermediate it will be found to occupy the same position.

Reviews

The Antiquity of Man in Europe. By James Geikie. New York: D. VanNostrand Co., 1914. Pp. 305. Illustrated.

As stated in the preface, this volume consists of a series of ten lectures delivered to a mixed audience and hence contains much elementary matter. It takes up first the migrations of the southern and temperate, the tundra or snow-loving, and the steppe fauna and flora in their relation to climatic changes in the Pleistocene epoch. The second and third lectures discuss cave deposits and human and animal relics and the archaeological stages of culture. The fourth lecture deals with river deposits and the succession of archaeological culture stages contained in them. A brief discussion of the loess and its relation to tundra and steppe conditions is also presented.

In chap. v, under the heading "Glacial Action," there is not only a discussion of glacial action proper, but also of the formation of screes, of the flowing soils of artic regions, and of the breccias of Gibraltar. Erosion of rock basins and overdeepening of valleys by glacial action is given prominence. In the following chapter, which deals with the glaciation of northern Europe, submarine basins in the Irish Sea and near the Hebrides, and the overdeepened valleys and fiords of Norway are referred to glacial action. Rock rubble in non-glaciated areas is also described. The thickness, extent, and direction of flow of the British as well as Scandinavian ice fields form the main theme. In chap. vii, the glaciation of the Alps and overdeepening of Alpine valleys and the glaciation of other mountains in middle and southern Europe are discussed; also the general climatic conditions of middle Europe in glacial and interglacial stages, and conditions favorable for loess deposition. The climatic conditions of the several interglacial stages and the different kinds of interglacial deposits are treated in the next chapter. The two concluding chapters deal with the history of the Pleistocene epoch, and the relation of the archaeological culture stages to the general glacial and interglacial stages. Estimates of geological time are briefly considered.

The volume is illustrated by 21 full-page plates of which 17 show characteristic animals, plants, and Paleolithic implements. The

remainder are photographs of Alpine scenes. There are also four small folded maps as follows: A. Europe during the second glacial epoch; B. Europe in interglacial times; C. Europe during the third glacial epoch; D. Europe during the fourth glacial epoch. The fourth glacial epoch as interpreted by Geikie corresponds to only the early part of the fourth or Würm Stage of Alpine glaciation. The fifth and sixth glacial stages of Geikie's classification seem likely to be represented in America by such strong readvances of the ice as the readvance to the Port Huron morainic system.

The aim of the author has been to deal with the question of the antiquity of man in Europe from the geological standpoint, and he maintains that it is chiefly by following geological methods of investigation that the successive stages of human culture are put on a firm and reliable basis. The discussion is restricted wholly to Europe with no reference to Asiatic invasions. In fact no intimation is given that the present people in Europe had any other line of descent than through the Paleolithic and Neolithic man. The earliest Paleolithic man is, on geological grounds, estimated to have appeared somewhere between 250,000 and 500,000 years ago. A more precise estimate is not considered possible in the present state of knowledge.

FRANK LEVERETT

ANN ARBOR, MICHIGAN

Twenty-second Annual Report of the Bureau of Mines, Ontario. Vol. XXII, Part I, 1913. By THOMAS W. GIBSON. Pp. 284, pls. 84, sketch maps 5, sheet maps 4.

This bulletin contains ten articles and reports. It commences with a review of the mining operations and production of the province during the year 1912. The value of the mineral output was $48,341,612—15 per cent greater than that of 1911. The decreasing production of the Cobalt region was compensated by a great enough rise in the price of silver to show an increase in the total value produced during the year. The Porcupine region added a million and three-quarters dollars' worth of gold to the annual output of the province. The year showed an increase in the output of both metallic and non-metallic minerals, but a much greater increase in the metallic.

The mines of Ontario are described by Mr. E. T. Corkell. He gives details of mine development, treatment of the ores, and production of the mines.

The geology of Whiskey Lake and the Massey Copper Mine area is reported upon by Dr. A. P. Coleman. The former workings were made first for copper and later for gold. The latter district has been worked for copper. Neither of the districts is commercially productive.

With the addition of the District of Patricia, the province of Ontario was given a location for a railway terminus at the mouth of Nelson River within territory formerly included in Manitoba. The location and surveying of this section are reported by Mr. J. B. Tyrrell. He describes his reconnaissance observations upon the agricultural and geological features of the parts of Patricia which he visited. In the northern part, the ancient crystalline rocks are overlain by fossil-bearing Ordovician and Silurian rocks. The Labradorean ice sheet deposited enough of a till covering upon the bared rocks of the northern part of the region to offer considerable agricultural possibilities. There are many instances of rock scorings of two glacial sheets. These are the Patrician and the Labradorean ice sheets. In Trout Lake region there is one set of striations which runs north 25° to north 40° west, planed and grooved by a glacier which moved south 40° west. The first striae were made by the Patrician glacier, which had its center in the highland southeast of Trout Lake; the later glaciation from the northeast was that of the Labradorean ice sheet. Upon the Hayes River, Mr. Tyrrell found evidence of the westward movement of the Patrician glacier followed by a southeastward advance of the Keewatin glacier. He considers, therefore, that the Patrician ice sheet preceded both the Labradorean and the Keewatin invasions in this region.

Mr. A. L. Parsons deals with the Lake of the Woods and other mineral areas in northwestern Ontario. He gives a detailed description of many of the ancient rocks of the region. A brecciated contact between granite bosses and Keewatin rock is common. The explanation offered is that the granite was intruded between the highly schistose layers of the metamorphosed Keewatin rocks. In most of the massive Keewatin rocks this contact breccia gives place to coarser, banded structure.

The West Shining Tree Gold area is described by Mr. R. B. Stewart. The rocks are chiefly of Keewatin age. The gold content is in quartz veins. The veins are very irregular in size and persistence; they are generally less than 4–6 feet wide and break into stringers. Many of the veins contain visible gold. A large amount of gold has been deposited along the fracture lines of the quartz, and a little in the bordering schists. The district is only in the very first stages of development.

"Glacial Phenomena of Toronto and Vicinity," by Dr. A. P. Coleman, and "Moraines North of Toronto," by Mr. Frank B. Taylor, are articles dealing with the glacial developments near the city of Toronto. The most interesting feature of the region is the Toronto interglacial formation which includes the Scarboro and the Don beds. The Don beds furnish many fossils of plants and shellfish. Among vertebrate fossils the remains of a bear, a bison, and two kinds of deer have been recognized. The whole assemblage of plants and animals implies a warmer climate than is there at present; one is implied comparable to the present climate of Ohio or Pennsylvania. The Scarboro beds have yielded fossils of 72 species of beetles and 3 mosses; these remains betoken a cool climate. During the Don interglacial period climatic conditions must have been such as to preclude the presence of an ice sheet within hundreds of miles of Toronto.

T. T. Q.

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1. *Glaciation of the Puget Sound Region.* By J. HARLEN BRETZ. Washington Geol. Survey Bull. 8. 1913. Pp. 244, pls. 24, figs. 27, maps 3.
2. *Bibliography of Washington Geology and Geography.* By GRETCHEN O'DONNELL. Washington Geol. Survey Bull. 12. 1913. Pp. 64.
3. *Geology and Ore Deposits of the Covada Mining District.* By CHARLES E. WEAVER. Washington Geol. Survey Bull. 16. 1913. Pp. 87, pls. 5, figs. 3.

1. The area studied stretches from the Canadian border 170 miles south to the divide between the Chehalis and Columbia rivers, and from the base of the Cascade Mountains to the Olympics, about 50 miles east and west. This region has been studied by several other geologists; but hitherto the glacial geology has not been so thoroughly treated as in this report. It is a detailed study of the region which discusses the Pleistocene history and later diastrophism. Terminal moraines, recessional moraines, extra-morainic outwash, the formation of glacial lakes, and drainage changes are the principal topics discussed in connection with the drift.

The submarine features are as remarkable as the surficial deposits. The region is characterized by deep marine channels or troughs. The greatest trough, that of Puget Sound, contains Admiralty Inlet, 60 miles

long and from 3 to 4 miles wide. For a distance of 45 miles its depth is between 575 and 900 feet below sea-level. The origin of the troughs is a subject which still requires further careful work. The author does not accept glacial erosion, drift deposition, or preglacial and interglacial stream erosion as the sole agents of the trough-making, but advances the opinion that each one, and in some cases all, of these have been causes of some of the troughs.

In Pleistocene times there were two glacial epochs, the Admiralty and the Vashon, with an interglacial epoch known as the Puyallup. The glacial invasions were both from the north. In the interglacial epoch there was an uplift of the region about 1,000 feet above the present level which was followed by stream erosion to submaturity stage. In postglacial times there has been submergence of 250 to 280 feet below present level and re-emergence.

2. The bibliography mentioned above is an expansion of the bibliography of Washington geology published by the Survey in 1910, and includes all publications up to date with an introduction of geographical material. It is provided with a full subject index.

3. The mining district covered by the third report is about 30 miles northwest from Spokane. The ore is argentiferous galena in quartz veins. Pay ore has been found in few places, and the output is very small.

T. T. Q.

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1. *Report of the Topographic and Geologic Survey Commission of Pennsylvania*, 1910–1912. By RICHARD R. HISE. Pp. 102, pls. 21, figs. 23, maps 5.

2. *Graphite Deposits of Pennsylvania*. By BENJAMIN L. MILLER. Topographic and Geologic Survey of Pennsylvania. Report 6. 1912. Pp. 143, pls. 17, map 1.

1. The first of these reports includes a bibliography of the publications of the state and of the United States Geological Survey relating to Pennsylvania. Other appendices are: "Preliminary Report on the York Valley Limestone Belt," by M. L. Jandorf; "Geological Origin of the Freshwater Fauna in Pennsylvania," by Dr. A. E. Ortmann; "A Peridotite Dike in Fayette and Greene Counties," by Lloyd B. Smith; "The Mineral Production of Pennsylvania," by R. R. Hise.

2. The report on graphite includes a general discussion of the history, properties, occurrence, and origin of graphite, with a full statement of its

distribution in the United States. It is concerned chiefly with the production, methods of mining, and manner of milling of graphite in Pennsylvania.

T. T. Q.

The Geography and Industries of Wisconsin. By RAY HUGHES WHITBECK. Wisconsin Geol. and Nat. Hist. Survey Bull. No. 26. 1913. Pp. 94, pls. 20, figs. 48.

This bulletin is essentially a geographical treatise on the natural resources of the state. It is designed primarily for use in the schools. The mineral production, forest industries, agriculture, manufacturing, and transportation are all in turn discussed with relation to indigenous opportunities and necessities. The volume is well calculated to meet the needs of those for whom it was written.

T. T. Q.

Krystallisationskraft. By RAPHAEL ED. LIESEGANG. Naturwissenschaftliche Umschau, No. 12, Beilage der Chemiker-Zeitung, 1913, Nos. 154, 155.

This article contains a brief summary of the work of various writers who have contributed, since 1836, opinions or experimental data on this subject. Mention is made of the work of Bruhns and Mecklenburg, who used potassium nitrate and alum solutions and reached the conclusion that capillarity and adsorption were probably more important factors than the force of the growing crystals. They found under conditions of alternate wetting and drying that the movement due to capillarity was actually complete before crystallization took place.

The author does not believe that the force of growing crystals can be considered a factor in geologic processes.

E. A. S.

Useful Minerals of the United States. By SAMUEL SANFORD and RALPH W. STONE. U.S. Geol. Surv. Bull. No. 585. Pp. 250. Washington, 1914.

This bulletin contains alphabetical lists of the useful minerals occurring in each of the states, with the localities in each state where each is found. A glossary and mineral index of thirty pages is appended.

A. D. B.

Mineral Resources of Southwestern Oregon. By J. S. DILLER. U.S. Geol. Surv. Bull. No. 546. Pp. 146, figs. 23, plates 10.

After a brief introductory chapter describing the general topographic and geologic features of southwestern Oregon, the writer proceeds to describe the gold-quartz lode mines, copper mines and prospects, placer mines, and the platinum, mercury, nickel, and coal resources of the region.

A. D. B.

Oil and Gas Fields in Wayne and McCreary Counties, Kentucky. By M. J. MUNN. U.S. Geol. Surv. Bull. No. 579. Pp. 105, figs. 6, plates 6. Washington, 1914.

About a third of the bulletin is devoted to the stratigraphy and larger structural features—the remainder is concerned with the history of production of oil, stratigraphy of the oil sands, and the details of the structure in the oil fields within the region. Structure contours are used to good advantage in the discussion.

A. D. B.

Handbuch der Mineral Chemie, Vol. II. By C. DOELTER. Pp. 848+xvi, figs. 37, plates 3. Dresden and Leipzig, 1912–14.

Proceeding with the detailed discussion of the chemistry of minerals (see review of Vol. I, *Jour. Geol.*, XXI, 465–67) this volume is concerned with quartz and the silicates. Practically all of the experimental work of recent years is included in a condensed and thoroughly digested form, and this volume should be exceptionally valuable as the chemistry of the silicates is only vaguely understood at present, and active research is being prosecuted along this line. Numerous tables of physical and chemical data are included, making reference to the original literature unnecessary in most cases. The detailed description of methods of synthesis which characterized Vol. I is continued throughout this volume, making it of great value as a reference work to the chemist as well as to the mineralogist.

A. D. B.

Ore Deposits in the Sawtooth Quadrangle, Blaine and Custer Counties, Idaho. By J. B. UMPLEBY. U.S. Geol. Surv. Bull. No. 580-K. Pp. 221–49, plates 4.

A report of the geology and ore deposits, based on a twelve days' reconnaissance trip. Silver-lead, silver, zinc, and gold veins have been worked more or less in the region but present production is negligible.

A. D. B.